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TIROS-N Series Direct Readout Services Users Guide

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FOREWORD

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LIST OF ACRONYMS AND ABBREVIATIONS

AFTN - Aeronautical Fixed Telecommunications Network

AGC - Automatic Gain Control

APT - Automatic Picture Transmission

ARRL - American Radio Relay League

ASECNA - Agency pour la Seceiri-te de la Navigation Ericanne

AVHRR - Advanced Very High Resolution Radiometer

AZ/EL - Azimuth/Elevation

CDA - Command and Data Acquisition

CEMES - Centre d'Etudes de la Meteorologie Spatiale

CO_2 - carbon dioxide

CNES - Centre National d'Etudes Spatiales

DCLS - Data Collection and Location System (also referred to as DCS - Data Collection System)

DCS - see DCLS

ESM - Equipment Support Module

ESSA - Environmental Science Services Administration also Environmental Survey Satellite

FANAS -- Forecast for Ascending Node for Automatic Satellites

GAC - Global Area Coverage

GMT - Greenwich Mean Time

GOES - Geostationary Operational Environmental Satellite

GT'S - Global Telecommunications Service

HEPAD - High Energy Proton and Alpha Detector

HIRS/2 - High Resolution Infrared Radiation Sounder

HRPT - High Resolution Picture Transmission

IMP - Instrument Mounting Platform

IOC - Index of Cooperation

IR - Infrared

ITOS - Improved TIROS Operational Satellite

keV - kiloelectron volts

LAC - Local Area Coverage

LST - Local Solar Time

MEPED - Medium Energy Proton and Electron Detector

MEV - megaelectron volts

MH_z - megahertz

MIRP - Manipulated Information Rate Processor

MSU - Microwave Sounding Unit

NASA - National Aeronautics and Space Administration

NESS - National Earth Satellite Service

NOAA - National Oceanic and Atmospheric Administration

O_3 - ozone

RSS - Reaction Support Structure

SEM - Space Environment Monitor

SR - Scanning Radiometer

SST - Sea Surface Temperature

ssu - Stratospheric Sounding Unit

TED - Total Energy Detector

TIP - TIROS Information Processor

TIROS - Television Infrared Observation Satellite

TOS - TIROS Operational Satellite

TOVS - TIROS Operational Vertical Sounder

VHF - Very High Frequency

VHRR - Very High Resolution Radiometer

VIS - Visible

VISSR - Visible/Infrared Spin Scan Radiometer

VTPR - Vertical Temperature Profile Radiometer

WEFAX - Weather Facsimile

GLOSSARY

ANOMALISTIC PERIOD OF SATELLITE: The time elapsing between successive passages of a satellite through the perigee.

APOGEE: The'point in its orbit at which the satellite is farthest from the center of the earth.

APSIS: The points in an elliptic orbit at which the radius vectors reach a maximum or minimum (e.g., perigee and apogee of a satellite orbit). The line joining these two points is called the line of apsides.

ARGUMENT OF PERIGEE: The geocentric angle of the perigee measured in the orbital plane from its ascending node in the direction of motion.

ARGUMENT OF SATELLITE: The geocentric angle of a satellite measured in the orbital plane from the ascending node in the direction of motion.

ARGUMENT OF SATELLITE AT MINIMUM (MAXIMUM) NADIR ANGLE: (See Argument of Satellite and Nadir Angle).

ASCENDING NODE (AN): The point at the equator at which the satellite in its orbital motion crosses from the southern to the northern hemisphere. Terrestrial Ascending Node (TAN) is given in degrees longitude. Celestial Ascending Node (CAN) is given on right ascension hours, minutes, etc.

ASCENDING NODE TIME: The time when the satellite passes the ascending node.

ATTITUDE (SATELLITE): The position of the axis of a satellite with respect to (a) its orbital plane, (b) the earth's surface, or (c) any fixed set of coordinates.

AZIMUTH (α): A horizontal direction expresses in degrees measured clockwise from an adopted reference direction, usually true north.

BULGE OF THE EARTH (R_E-R_P): The.difference between the equatorial and the polar radii of the earth.

CELESTIAL: The prefix to designate lines or points which have been projected onto the celestial sphere by means of the radials through the center of the earth.

CELESTIAL EQUATOR: The great circle along which the plane of the earth's equator intersects the celestial sphere.

CELESTIAL SPHERE: An imaginary sphere of infinite radius with its center located at the observer or at the center of the earth. In satellite meteorology the center of the celestial sphere is at the center of the earth. Lines or points are projected onto the celestial sphere using radials through the center of the earth.

CELESTIAL **SUBSATELLITE POINT:** A point on the celestial sphere the declination of which is identical to the geocentric latitude of TSP and the right ascension of that of TSP. (See **SUBPOINT** TRACK.)

DATA ACQUISITION **STATION (CDA):** A ground station at which various functions to control satellite operations and to obtain data from the satellite are performed. The CDA transmits programming signals to the satellite, and **commands** transmission of data to the ground.

DECLINATION (6): The angular distance of an object north **(+)** or south **(-)** from the celestial equator measured along the hour circle passing through the object.

DEGRADATION: The lessening of picture image quality because of "noise," or any optical, electronic, or mechanical distortions in the image-forming system.

DESCENDING NODE **(DN):** The southbound equator crossing of the satellite; given in degrees longitude, date, and time for any given orbit or pass.

DIRECT ORBIT: The orbit with inclination between Oo and 90° measured counterclockwise from the equator. Same as the **prograde** orbit.

DISTORTION: An apparent warping and twisting of a picture image received 'from a satellite. This distortion has two causes: electronic and optical. "Electronic Distortion" is caused by imperfections in the circuitry, the tape recorder, the vidicon tube structure, the transmission system, or the signal characteristics. "Optical Distortion" is caused by the characteristics of the lens and optical alignment.

ECLIPTIC: The great circle in which the plane of the earth's orbit intersects the celestial sphere.

EQUATORIAL ORBIT: Orbit with ***zero* degree** inclination.

GAMMA: Gamma is the angle at the satellite between the satellite spin-axis and the satellite-sun line.

HEADING LINE: The instantaneous projection of the spacecraft velocity vector on the earth's surface.

IMAGE PRINCIPAL LINE: (See Principal Line).

INCLINATION (OF SATELLITE ORBIT): (See Orbit Inclination).

LATITUDE-LONGITUDE GRID: A latitude-longitude grid is a form of perspective grid in which the quadrilaterals are latitudes and longitudes.

LOCAL VERTICAL: A line perpendicular to the surface of the earth.

NADIR ANGLE: The angle measured at the satellite between a specific axis or ray and the local vertical.

NODE: The points at the equator at which the satellite in its orbital motion crosses the equator. The line connecting the ascending and the descending nodes is called the line of nodes.

NODAL PERIOD: The time elapsing between successive passages of the satellite through successive ascending nodes.

NODAL INCREMENT: Degrees of longitude between successive ascending nodes.

NOISE: A voltage received through an antenna system or within the ground amplifier and other electronics that does not correspond to any intended signal.

OBJECT SPACE ANGLE: The angle between two rays in space that intersect at the front nodal point of a camera lens.

OPTICAL AXIS: A straight line passing through the front and rear nodal points of a camera lens. The direction on the axis is considered positive from the rear to the front nodal points.

OPTICAL AND ELECTRONIC DISTORTIONS: (See Distortion.)

ORBIT: The path which a celestial object follows in its motion through space, relative to some selected point.

ORBIT INCLINATION: The angle between the plane of the satellite orbit and the earth's equatorial plane. Inclination of retrograde orbit is expressed by 180 degtees minus the prograde inclination.

ORBIT NUMBER: In satellite meteorology orbit number refers to a particular circuit beginning at the satellite ascending node. The orbit number from launch to the first ascending node is designated zero, thereafter the number increases by one at each ascending node.

ORBITAL PLANE: The plane, or two dimensional space which contains the path of an orbiting satellite.

ORBIT, POLAR: An orbit which passes directly over both the geographic poles of the earth.

ORBIT, SUN-SYNCHRONOUS: (See Sun-Synchronous Orbit.)

PERIGEE: The point in its orbit at which the satellite is closest to the center of the earth.

PERIGEE RATE: Rate of change of the argument of perigee. It -is usually measured in degrees per day.

PRECESSION RATE ( ): The fixed space angular motion of the orbital line of nodes; positive to the East, negative to the West. Precession rate for a sun-synchronous orbit is -0.986 degrees per day.

PITCH: Angular deviation of the camera axis from the vertical along the orbital plane at the time of picture taking.

PRINCIPAL DISTANCE: The distance measured along the optical axis either from the nodal point or the interior perspective center to the image or target plane.

PRINCIPAL LINE: A line of intersection between the principal plane and the image plane (Image Principal Line), or principal plane and the earth.

PRINCIPAL PLANE: The plane-which'includes the optical axis of a camera and the local vertical through the front nodal-point of a satellite camera lens.

PRINCIPAL POINT: The point of intersection of the optical axis of the camera with the image plane, or with the earth.

PROGRADE ORBIT: (See Direct Orbit.)

R/O: Abbreviation for readout orbit.

RADIOMETER: A scanning sensor that operates continuously, each scan line sweeping across the earth from horizon-to-horizon along a path normal to the direction of travel of the spacecraft.

RASTER: The pattern followed by the electron-beam exploring-element scanning the screen of a television transmitter or receiver. The scanning pattern is, theoretically, a series of straight parallel lines.

RASTER LINE: One scan line of a TV (Vidicon) system.

READ-OUT STATION: (See Data Acquisition Station.)

RESOLIJTION: The ability of a film, a lens, a combination of both, or a vidicon system to render barely distinguishable a standard pattern of black and white lines. When the resolution is said to be 10 lines per millimeter, it means that the pattern whose line-plus-space width is 0.1 mm is barely resolved, the finer patterns are not resolved, and the coarser patterns are more clearly resolved.

RETROGRADE ORBIT: The orbit with inclination between 0° and 90° measured clockwise from the equator when viewed from the north.

RIGHT ASCENSION: The arc measured eastward along the celestial equator from the Vernal Equinox to the great circle passinq through the celestial poles and the object projected onto the celestial sphere. This angle is frequently given in hours and minutes--24 hours equivalent to 360 degrees.

ROLL: Angular deviation of the satellite axis from the plane tangent to the orbital plane.

SCANLINE: One sweep of a radiometer across the earth from horizon-to-horizon.

SUBPOINT TRACK: Locus of subsatellite points on the earth (TSP), on an image, or on a celestial sphere.

SUBSATELLITE POINT: Intersections of the local vertical passing through the satellite with the earth's surface, with the image plane and with the celestial sphere.

SUBSOLAR POINT (SS): Intersection of the local vertical through the sun with the surface of the earth.

SUN-SYNCHRONOUS ORBIT: Nominally a retrograde; quasi-polar orbit such that the satellite crosses the equator on the ascending node always at the same local (solar) time.

SYNCHRONOUS SATELLITE: A satellite in a west-to-east orbit of the earth at an altitude of 22,300 statute miles. At this altitude it circles the axis of the earth once in 24 hours. Thus its speed in orbit is synchronous with the earth's rotation.

TERRESTRIAL: The term used to designate a line or a point on the earth's surface.

TIME PAST ASCENDING NODE: The amount of time for a body in orbit to advance from the last ascending node to an arbitrary position.

TIME PAST PERIGEE: The amount of time for a body in orbit to advance from the last perigee to an arbitrary position,

TRACK: A line connecting successive positions of a moving point.

VERNAL EQUINOX: (Also called the Right Ascension of Aries.) The point of intersection of the celestial equator with the ecliptic, at the point where the sun crosses from the south to the north side of the equator.

1. INTRODUCTION TO THE TIROS-N SYSTEM

1.1 History of the United States Meteorological Satellite Program

The National Earth Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) operates a network of polar and geostationary satellites that provide data used to meet some of NOAA's responsibilities.' These satellite data products are used for meteorological prediction and warning, oceanographic'and hydrologic services, and space environment monitoring and prediction. The two satellite systems (polar and geostationary) are complementary, each having been designed to meet mission requirements for which it is uniquely qualified. For example, continuous monitoring of storm areas in the temperate and tropical latitudes is primarily a geostationary satellite mission, whereas data collection at higher latitudes is an objective of a polar orbiting satellite.

The launch of TIROS-N from the Western Test Range at Lompoc, California, on 13 October 1978 introduced the third generation operational, polar orbiting, environmental satellite system. The new TIROS-N system has evolved from the world's first meteorological satellite, TIROS-1, which was launched into orbit on 1 April 1960 from Cape Canaveral, Florida. The early TIROS experimental spacecraft series (TIROS l-10) was followed by the TIROS Operational Satellite (TOS) series (ESSA 1-9). This series was introduced on 3 February 1966 with the launch of ESSA-1. These "wheel-type" TOS satellites were designed to fill the need for a relatively low cost, fully operational weather satellite system to provide worldwide photographic coverage of the earth and its atmosphere. In effect, this satellite "rolled" along its orbit on its rim as a wheel would roll along the earth's surface.

The Improved TIROS Operational Satellite, ITOS-1, was launched on 23 January 1970 and ushered in the second generation of operational polar orbiting satellites. It dramatically exceeded the capabilities of the first generation TOS system. The last of the ITOS series spacecraft, NOAA-S, was launched on 29 July 1976.

As the potential advantages of observations from space were recognized, evolving requirements brought about changes in the satellite instrumentation. The Automatic Picture Transmission (APT) service, tested experimentally on TIROS-8 in 1963 and on Nimbus-l in 1964, became a continuing service with the launch of ESSA-2 in 1966. Vidicon cameras, the primary source of data for both the central processing and the APT service, were replaced by radiometers on NOAA-2, launched in 1972. At the same time, the High Resolution Picture Transmission (HRPT) service was begun, making data from the Very High Resolution Radiometer (VHRR) instrument available to local readout stations with the proper receiving equipment. The NCAA-2 spacecraft also included a Vertical Temperature Profile Radiometer (VTPR) instrument as a part of the payload; this instrument, based on technology tested on research satellites, was the first operational vertical sounder to be flown.

The instrumentation for TIROS-N has been selected based on the NOAA satellite program philosophy of meeting operational requirements for products with instruments whose potential has been proven in space. Predecessor instruments have flown experimentally on both Nimbus and ITOS satellites. These instruments have been redesigned to meet both scientific and technical requirements of the mission; the goal of the redesign has been to improve the reliability of the instrument and the quality of the data without changing the previously proven concepts.

1.2 The TIROS-N Concept

The spacecraft of the TIROS-N series incorporate new environmental instruments that are major technological advances over those on board the ITOS series spacecraft they have replaced. New capabilities offered by the TIROS-N series include: improved day and night cloud cover observations on a local and global scale, improved observations of vertical temperature and water vapor profiles on a global scale, and a high capacity data collection, relay, and platform location system.

In the TIROS-N operations concept, two spacecraft are always in operation. One spacecraft passes over in the morning between 0600 and 1000 local time; the other spacecraft passes over in the afternoon, about 1500 local time. The. initial spacecraft of the series, designated TIROS-N, was placed into the afternoon orbit; NOAA-6, the second spacecraft of the series, was placed in the 0730 local southbound orbit on 27 June 1979. With the exception of TIROS-N, all satellites of the series will be designated by letter before launch, but will be numbered consecutively after launch.

Four pairs of spacecraft are planned for the series through 1985, launched roughly at the rate of one pair every two years after the launches of TIROS-N and NOAA-6. NOAA-G, the last satellite planned for this series, is currently scheduled for launch in May 1984 and thus will ensure polar satellite services into 1986. Initial planning has begun for the fourth generation of polar spacecraft to be ready by 1985 to continue the uninterrupted acquisition of data from the earth's atmosphere, from its surface, and from within its near space.

The TIROS-N series of satellites is a cooperative effort of the United States, the United Kingdom, and France. The National Aeronautics and Space Administration (NASA) funded the development and launch of the initial satellite of the series (TIROS-N); subsequent satellites will be procured and launched by NASA using NOAA funds. The operational ground facilities, including the Command and Data Acquisition (CDA) stations, the Satellite Control Center, and the data processing facilities (with the exception of the Data Collection System (DCS)* processing facility) are funded and operated by NOAA. The United Kingdom, through its Meteorological Office, Ministry of Defense, is providing a Stratospheric Sounding Unit (SSU), one of three sounding instruments for each satellite. The Centre National d'Etudes Spatiales (CNES) of France is providing the DCLS instrument for each satellite and provides the facilities necessary to process and make available to users the data obtained from this system. The

*The DCS is also referred to as the Data Collection and Location System (DCLS) in some documents.

Centre d'Etudes de la Meteorologie Spatiale (CEMES) of France provides ground facilities for receipt of sounder data during the blind orbit periods.

1.3 TIROS-N Spacecraft Characteristics

The TIROS N spacecraft, as shown in Figure l-l, is a five-sided box-like structure that is 3.71 meters long and 1.88 meters in diameter. Four of the side faces are equal in size and accommodate thermal control louvers. The fifth side is wider than the other four and accommodates the earth-facing communications antennae and some of the earth-viewing sensors. The spacecraft weighs a total of 1,409 kilograms (kg) at launch, including expendables.

At the end of the central body, known as the Equipment Support Module (ESM), is the Reaction Support Structure (RSS), which includes the last stage launch injection motor, an attitude control propulsion system, and a boom-mounted solar cell array. The solar array is 11.6 square meters (m^2) and is motor driven to rotate once per orbit to enable it to face the sun continuously during the daylight portions of the orbit.

At the other end of the ESM is the highly stable Instrument Mounting Platform (IMP) on which are mounted the attitude control sensors and the instruments whose scan directions must be very accurately controlled. With'the exception of the Space Environment Monitor (SEM), all instruments face the earth when the satellite is in its mission mode. The earth-oriented platform is controlled to within 0.2° of the local geographic reference for all axes.

A most important spacecraft subsystem is the data handling subsystem, which consists of the following components:

1) TIROS Information Processor (TIP),
2) Manipulated Information Rate Processor (MIRP), and
3) digital tape recorders.

TIROS-N Spacecraft

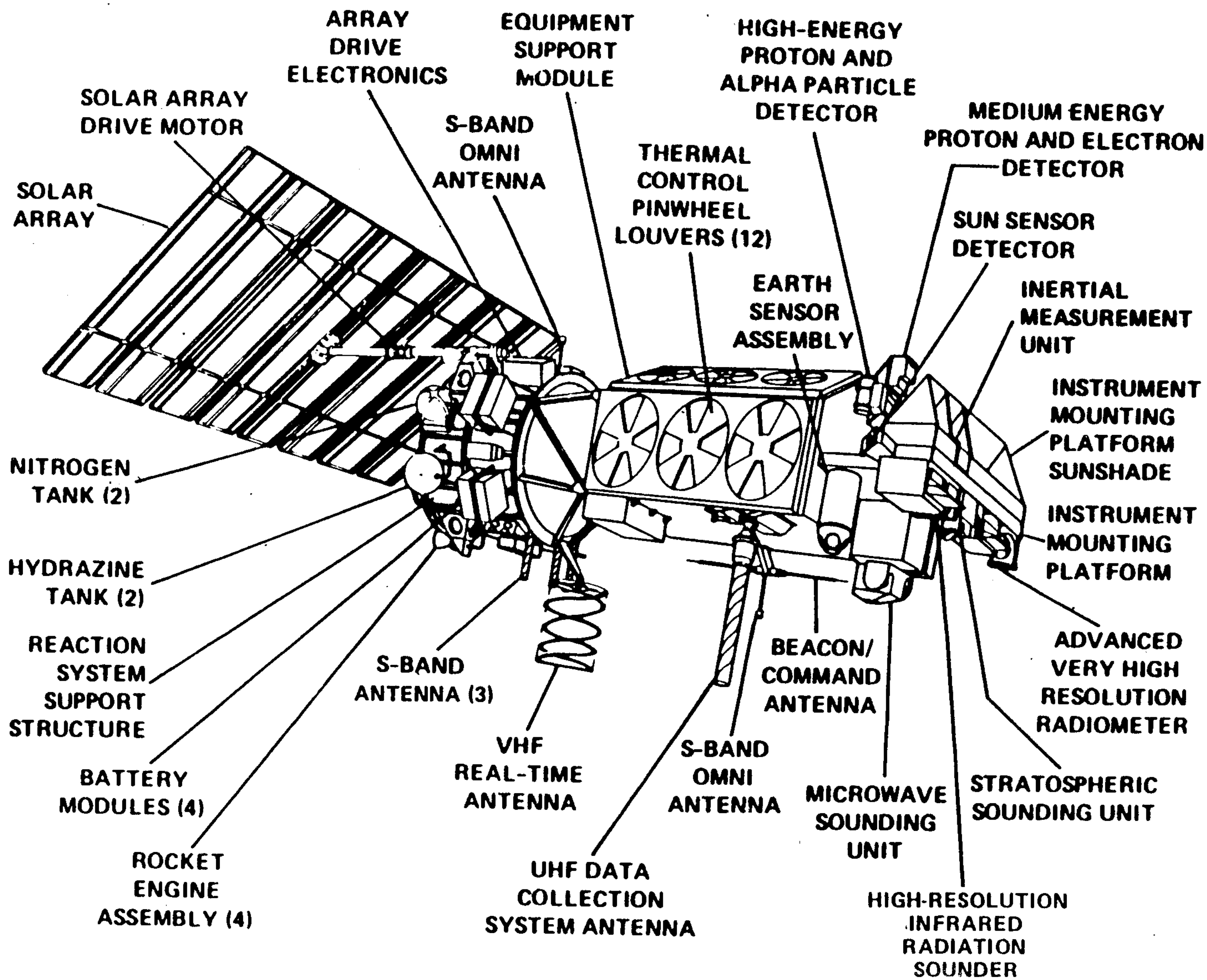


Figure 1-1 TIROS-N Spacecraft Characteristics

All data available for transmission to the ground are processed by some or all of these components. The TIP formats all low bit-rate instruments and housekeeping telemetry data and controls the data outputs. The MIRP processes the high bit-rate data from the Advanced Very High Resolution Radiometer (AVHRR) to provide separate outputs for APT and HRPT transmissions in real time, recorded Global Area Coverage (GAC) of reduced resolution data for central processing, and recorded Local Area Coverage (LAC) of high resolution data also for central processing.

2. DESCRIPTION OF THE TIROS-N SENSOR PACKAGE

The four primary TIROS-N spacecraft instrument systems are listed below:

- Advanced Very High Resolution Radiometer (AVHRR)
- TIROS Operational Vertical Sounder (TOVS)
- Data Collection System (DCS)
- Space Environment Monitor (SEM)

2.1 Advanced Very High Resolution Radiometer

The AVHRR provides data for real-time transmission to both API and HRPT users and for storage on the spacecraft tape recorders for later playback. Thus, the AVHRR instrument continues end improves the ITOS/NOAA satellite services related to stored and direct readout of radiometric data for day and night cloud mapping, sea surface temperature mapping, and other oceanographic and hydrologic applications. The data from the AVHRR instrument are available from the satellite in four operational modes:

1) APT (Automatic Picture Transmission): direct readout to worldwide ground stations of the APT visible and infrared data (4 km resolution); panoramic distortion is removed.
2) HRPT (High Resolution Picture Transmission): direct readout to worldwide ground stations of the HRPT data for all spectral channels (1.1 km resolution).
3) GAC (Global Area Coverage): global on-board recording of 4 km resolution data from all spectral channels for commanded readout for processing in the NOAA central computer facility at Suitland, Maryland.
4) LAC (Local Area Coverage): on-board recording of data from selected portions of each orbit at 1.1 km resolution of all spectral channels for central processing.

The AVHRR for TIROS-N and the four follow-on spacecraft is sensitive in four spectral regions (see Table 2-l). A future change in the instrument design will add a fifth channel in the 12 micrometer (m) region. The resulting five-channel instruments are thus planned for flight on later spacecraft in the series. The four-channel radiometer is designated the AVHRR/1 instrument; the later, five channel radiometer is the AVHRR/2 instrument.

AVHRR Channels 1 and 2 can be used to discern clouds, land-water boundaries, and snow and ice extent; when data from the two channels are compared, an indication of ice/snow melt inception is provided. The data from Channel 4 (infrared (IR) window) can be used to measure cloud distribution day and night and to determine the temperature of the radiating surface. Channels 3 and 4 can be used to determine the sea surface temperature (SST). By using these two data sets, it is possible to remove an ambiguity introduced when clouds fill a portion of the field-of-view. Examples of imagery from the AVHRR instrument are given in Section 7.

2.2 Other TIROS-N Sensors

2.2.1 TIROS Operational Vertical Sounder

Data from the TOVS, which is a three-instrument system, are available locally as a part of the HRPT transmission and on the spacecraft beacon transmission. The three TOVS instruments are as follows:

- The High Resolution Infrared Radiation Sounder (HIRS/2)--a 20-channel instrument making measurements primarily in the IR region of the spectrum. The instrument is designed to provide data that will permit calculating (1) temperature profile from the surface to 10 millibars (mb), (2) water vapor content in three layers in the atmosphere, and (3) total ozone (O_3) content. The design is based on the HIRS instrument flown on the Nimbus satellite.

TABLE 2-1

TIROS-N AVHRR CHANNEL CHARACTERISTICS

Channel*	Resolution at Subpoint (km)	Wavelength (μm)	Primary Use
1	1	0.55 - 0.90	Daytime cloud and surface mapping
2	1	0.725 - 1.10	Surface water delineation
3	1	3.55 - 3.93	Sea surface temperature (SST), nighttime cloud mapping
4	1	10.5 - 11.5	SST, day/night cloud mapping
5	1	11.5 - 12.5	SST

*Channel 1 wavelength will be 0.58 to 0.68 μm for all instruments after the TIROS-N flight model. Channel 4 wavelength will be 10.3 to 11.3 μm for all AVHRR/2 instruments. Channel 5 will not be on early AVHRR/1 flights but will be added with the AVHRR/2 instruments to enhance further SST measurements in the tropics. The AVHRR/2 instrument will be flown on all later spacecraft of the series; users will be notified when this change takes place.

- The Stratospheric Sounding Unit (SSU)--using a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel are determined by the pressure in a carbon dioxide (CO_2) gas cell in the optical path. The amount of CO2 in the cells determines the height of the weighting function peaks in the atmosphere. The primary objective of this instrument is to obtain data from which stratospheric (25 to 50 km) temperature profiles can be obtained.
- The Microwave Sounding Unit (MSU)--a 4-channel Dicke radiometer, making passive measurements in the 5.5-millimeter (mm) oxygen band. The microwave data will permit computations to be made in the presence of clouds since measurements in this region are generally unaffected by nonprecipitating water droplets.

2.2.2 The Data Collection and Location System

The DCS is a random access system that acquires data from fixed and free-floating terrestrial and atmospheric platforms. Platforms can be located by ground processing the Doppler measurements of carrier frequencies. Data collected from each platform include identification, as well as environmental, measurements. These data are also included in the HRPT and beacon transmissions.

2.2.3 The Space Environment Monitor

The SEM data are also included in the HRPT and beacon transmissions. The SEM consists of three separate instruments and a data processing unit.

- The total energy detector (TED) measures a broad range of energetic particles from 0.3 kiloelectron volts (keV) to 20 keV in 11 bands.

- The medium energy proton and electron detector (MEPED) senses protons, electrons, and ions with energies from 30 keV to several tens of megaelectron volts (MEV).
- The high energy proton and alpha detector (HEPAD) senses protons and alphas from a few hundred MEV up through relativistic particles above 840 MEV.

3. ORBITAL CONSIDERATIONS

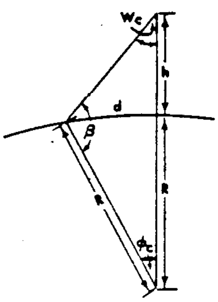
3.1 General Aspects of Orbits and Their Effects

When plans are made to place a meteorological satellite in orbit, three factors must be considered to decide how best to meet the mission requirement of daily global coverage: the area of view of each sensor, the orbital period and its relationship to the frequency and spatial continuity of observations, and the resolution of detail within the field of view of each sensor.

3.1.1 Coverage

The TIROS-N AVHRR is a line-scanning radiometer, similar to the scanning radiometer (SR), which has provided data from the ITOS series of satellites to APT users. Unlike the earlier APT camera, which takes a picture and transmits it by slowly scanning a vidicon tube, a scanning sensor operates continuously, each scan line sweeping across the earth from horizon to horizon along a path normal to the direction of travel of the spacecraft.

The geometry involved in computing the area that can be seen by a spacecraft sensor is shown in Figure 3-1. For a line scan system, angle W_c is limited to the area at right angles to the satellite heading line. The area viewed by a single scan line is essentially perpendicular to the direction in which the spacecraft is moving and has a component in the direction of movement equal to the line width on the earth. Swath length is equal to the distance traveled by the spacecraft over the earth in the time given.



W_c is the angle of view

ϕ_c is the geocentric angle to intersection of W_c on earth

R is the radius of earth

h is the spacecraft altitude

d is the distance on earth from subpoint to picture point for viewing angle W_c

Figure 3-l Diagram for Computing Area Viewed by Satellite

When a line-scan instrument is pointed normal to the earth's surface and scans outward to an angle W_c, the overall area viewed (swath width) depends on spacecraft height alone; the higher the satellite, the larger the area viewed. Using Equations 1 through 3, the area viewed can be computed.

$$\sin \beta = \frac{(R+h)}{R} \sin W_c \tag{1}$$

$$\phi_c = 180 - (W_c + \beta)$$

$$d = \phi_c \times 111 \text{ kilometers (km)} \tag{3}$$

For example, at a satellite altitude of 1,387 km and a maximum viewing angle of 45^o ($W_c = 45^o$), the area viewed is approximately 1,604 km from center to side; at a 740 km altitude it is approximately 786 km. For the TIROS-N series, the swath width is approximately 2,700 km (full side to side swath width).

3.1.2 Orbital Period

The orbits of earth satellites, whether natural or manmade, are controlled by the same physical laws. A satellite in orbit follows a path that is the result of balanced forces; the acceleration of gravity on the satellite is exactly balanced by the outward component of the tangential linear velocity. The requirement for the existence of this balance permits the computation of the orbital speed and, hence, the orbital period of a satellite for any given height. The orbit period T for a near circular orbit is:

$$T = 84.4\left(1 + \frac{h}{R}\right)^{3/2} \text{minutes,} \tag{4}$$

where h is the altitude of the satellite and R is the radius of the earth. Thus, as h increases, T increases, as shown in Table 3-1.

TABLE 3-1

RELATIONSHIP OF ORBITAL PERIOD

TO SPACECRAFT ALTITUDE

Altitude		Orbit/Period
h (km)	h (NM)'	T (minutes)
371	200	91.9
854	460	102.0
1,112	600	107.4
1,390	750	113.5
1,462	790	115.1
35,790	19,312	1,440 (Synchronous altitude?

Because the orbit plane is essentially "fixed" in space for short time periods and the earth rotates within the orbit, the orbit period (T) determines the longitudinal distance between successive equatorial crossings. Thus, for 'a satellite orbit of 100 minutes, this longitudinal distance is 25 degrees (one degree per four minutes.) For example, if equator crossing "n" takes place at 75 degrees W, the next crossing (n + 1), 100 minutes later, will be at 100 degrees W. This fact provides the basis of orbital position computations used in tracking and gridding procedures discussed later.

The altitude of the satellite thus determines the time difference and the longitudinal distance (ϕ_E) between successive equatorial crossings. If the data acquired on successive orbits are to be contiguous (just touch) at the equator, the swath width measured in geocentric angles ϕ_e - (ϕ_c at edge of swath) must equal the longitudinal distance between successive equator crossings. If contiguity is not possible at the equator ($\phi_e < \phi_E$), the lowest latitude (λo) at which contiguity occurs is where λo equals $\cos^{-1}$ (ϕ_e/ϕ_E). Data swaths that just touch at the equator overlap by about 30% at 45 degrees of latitude.

3.1.3 Resolution

For a given spacecraft altitude, the resolution of a line-scan device, such as the AVHRR, is a function of the instantaneous field-of-view of the sensor (spot size on the earth). As the sensor scans outward from the satellite subpoint, the spot size on the surface of the earth, of course, increases in size. The TIROS-N AVHRR has a field-of-view of 1.3 milliradians; at this field-of-view, the subpoint resolution is 1.1 km and the resolution at the edge of the data swath is approximately 4 km.

3.2 Selection of Orbit

A near polar, sun-synchronous orbit has been chosen for meteorological satellites with real-time transmission systems because it offers the best geometry for routine coverage on a regular basis, A sun-synchronous orbit maintains the satellite in a relatively constant relationship to the sun so that the ascending node (northbound equator crossing) remains at a constant solar time, thus permitting receipt of data at approximately the same local time each day. The choice of time of day is based on meteorological and spacecraft operating considerations; no change is possible once the spacecraft has been launched.

The nominal orbital parameters of the TIROS-N satellite series are summarized in Table 3-2. For comparison, the orbital parameters of the previous ITOS series (NOAA-1 through NOAA-S) are also given. The TIROS-N series has been designed to operate in a sun-synchronous orbit. The two nominal altitudes shown in Table 3-2 have been chosen to keep the orbital periods of two operational satellites in similar orbits sufficiently different (l-minute) so that they do not both view the same point on the Earth at the same time each day for prolonged periods.

A satellite pass directly over an antenna site will be within view of that antenna (horizon-to-horizon) for about 15.5 minutes when the satellite is at 833 km and 16 minutes when it is at 870 km. The user of ART or HRPT can therefore expect to receive data from a

TABLE 3-2

NOMINAL ORBITAL PARAMETERS FOR TIROS-N SERIES
AND NOAA SERIES SATELLITES

Satellite	Orbit (km)	Inclination (degree)	Nodal Period (minutes)	Nodal Regression (degree/degree W)	Orbits per Day
TIROS N Series	833	98.739	101.38	25.40	14.18
	870	98.899	102.37	25.59	14.07
NOAA Series	1451	101.6	115.01	28.8	12.5
	1512	102.6	116.2	29.1	12.4

circular area 6,200 km in diameter centered at the location of the antenna. If one assumes that the spacecraft must be 5 degrees above the horizon for useful data to be acquired, the contact times are reduced to about 13.0 minutes (833 km satellite altitude) and 13.7 minutes (870 km); the area is reduced to 5,200 km in diameter.

Because the number of orbits per day is not an integer number, the sub-orbital-tracks do not repeat from day to day, although the local solar time for passing any latitude is essentially unchanged. For this reason, the orbital-equator crossings will occur at varying longitudes during the lifetime of the satellite.

NOAA/NESS currently operates two CDA stations, one in Virginia and one in Alaska, to receive the environmental data from the satellite. During three sequential orbits of the Earth (four, some days), however, the satellite remains out of contact with one of these sites. To eliminate delay in receipt of high priority vertical temperature profile data during this period, a data receipt-only station has been established to receive data in Lannion, France, by CNES. This station will acquire stored TIP data and transmit it to the central processing,facility in the United States. when this station is in use, the satellite will be out of contact with the ground for no more than one orbital period per day.

3.3 Equator Crossing Time

The TIROS-N satellite series has been designed to operate with a southbound equator crossing between 0600 and 1000 Local Solar Time (LST), or a northbound equator crossing between 1400 and 1800 LST (Figure 3-2). Power and thermal constraints preclude normal operation within two hours of noon or (midnight) LST. The time of day actually chosen for the initial injection condition for a particular satellite depends on several factors:

- time of day that data are needed for input to synoptic map analyses,
- subpoint solar angles for visible channel instruments,
- orbital plane separation from secondsatellite in orbit,

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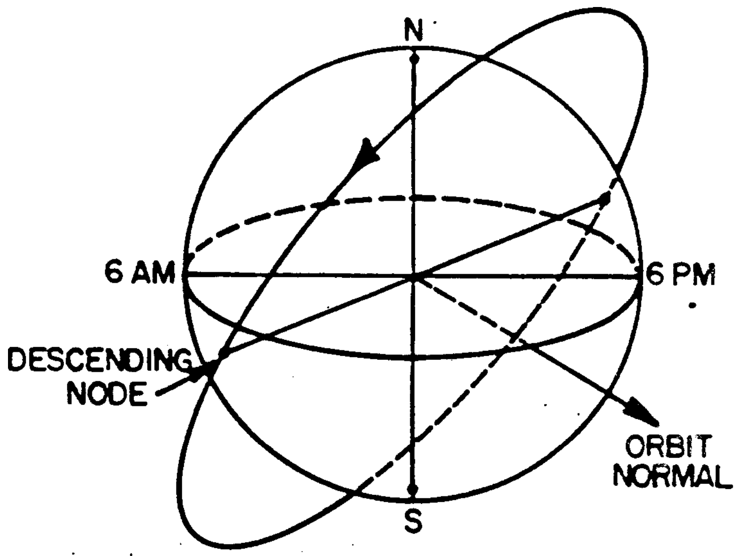
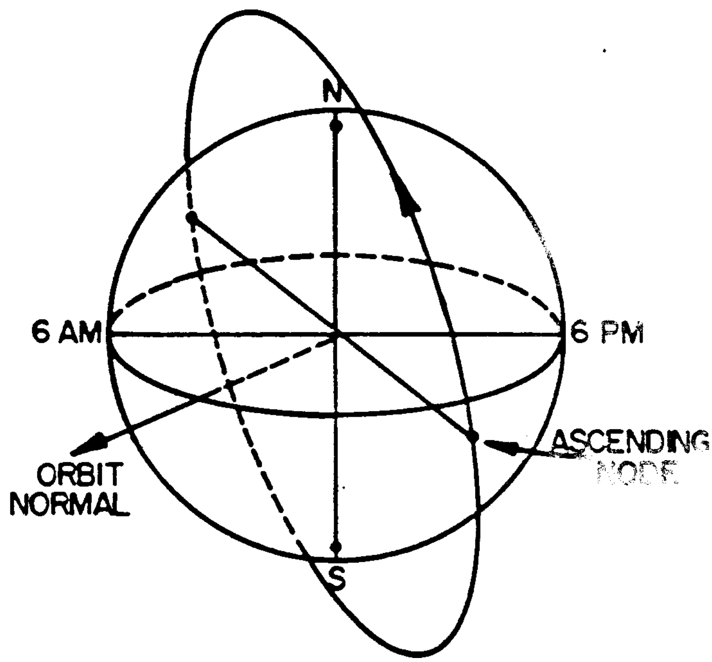
- orbital plane separation from second-satellite in orbit,



AM DESCENDING NODE ORBIT



PM ASCENDING NODE ORBIT

Figure 3-2 TIROS-N/NOAA Equator Crossing Times

- expected drift from sun-synchronous conditions and spacecraft time of day (solar angle) constraints, and
- time of year launch will occur.

3.4 Effects of Precession of Orbital Plane

3.4.1 Sun-synchronous Orbits with Earth-Oriented Sensors

A satellite traveling in a sun-synchronous orbit can acquire images of any given area at the same local sun time each day. To maintain this sun-synchronous operation from week to week, it is necessary that precession $\dot{\Omega}$ of the orbital plane be 360^{o} in 365 days to compensate for the earth's seasonal travel around the sun. Precession is a function of satellite altitude and orbital inclination and is given by the expression

$$\dot{\Omega} = 10.0\ a^{-3.5} \cos i \text{ (degrees/24 hours)} \tag{5}$$

where i is the orbital inclination to the equator, $a = (1 + h/R)$, R = 6,364 km, and h is average satellite height. The desired precession is achieved when the sun-synchronous inclination i_{ss} is such that:

$$\cos i_{ss} = 0.0986 \left(1 + \frac{h}{R}\right)^{3.5} \tag{6}$$

Note that if the standard sign convention is followed, sun-synchronous precession is achieved when $\dot{\Omega}$ has the negative value -0.986 and i_{ss} is greater than 90^{o} (a retrograde orbit). However, sun-synchronous may be taken to be positive, and the symbols i and i_{ss} for inclination are then defined to be the acute angle between the equatorial and orbital planes for a retrograde orbit.

The orbital inclination also defines the maximum geocentric latitude (north and south) reached by the satellite subpoint on each orbital pass. The maximum poleward excursions for sun-synchronous inclination for various satellite altitudes are:

- at h = 833 km (450 nm), iss = 81.1°,
- at h = 1,110 km (600 nm), iss = 79.9°,
- at h = 1,388 km (750 nm), i_{ss} = 78.6°, and
- at h = 1,850 km (1,000 nm), i_{ss} = 75.9°.

3.4.2 Drift from Sun-synchronous Conditions

Orbit parameter errors result from several causes associated with the booster operation. These errors may be characterized as either orbital plane (inclination) or altitude related. Orbital parameters for the TIROS-N series are expected to be within the following three sigma limits:

- altitude (average): ±18.5 km,
- inclination: 0.15°, and
- apogee/perigee difference: less than 56 km.

After injection, solar forces (gravity and event effects) will cause the inclination to change from that originally achieved. The effect of this change, combined with the initial injection errors will probably cause the nodal precession rate to deviate from that required for true sun synchronism. Whether the local solar time becomes earlier or later depends on the sign of the error. It is apparent that initial drift will be a factor of the accuracy of injection into orbit; changes after this drift is defined will be caused by solar effects.

3.5 Spacecraft Track over the Earth

In the early 16009, Johann Kepler discovered the physical laws that control the paths and motions of satellites in orbit. Those laws forming the basis of computations at the local site are as follows.

- The orbit of each planet (satellite) is an ellipse with the sun (earth) always located at one focus.

- Each planet (satellite) moves in an orbit so that an imaginary line drawn between the planet (satellite) and the sun (earth) sweeps out equal areas in equal times (see Figure 3-3).

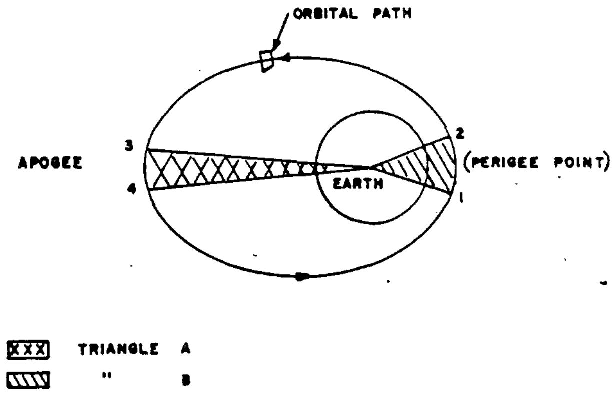


Figure 3-3 Diagram of Elliptical Orbit

The area of A will equal the area of B when the-time required for moving from 1 to 2 is equal to the time required for moving from 3 to4.

In a perfectly circular orbit *at* any given altitude, *a spacecraft* moves above the surface of the earth at a constant velocity. In actual practice, no earth orbit is perfectly circular, although some may approach this condition. In an earth satellite's orbital ellipse, the point of closest approach to the earth is called perigee, whereas the point farthest from the earth is the apogee. The initial positions of apogee and perigee are determined by the launch characteristics; subsequently, the positions of apogee and perigee advance gradually around the orbit as a result of the gravity effect of the equatorial bulge of the earth.

The change in the positions of perigee and apogee cause the height at which the spacecraft passes over a given region of the earth to vary with time (see Figure 3-4). Daily messages will reflect changes in the position of apogee and perigee.

For convenience and ease of computations, the time the spacecraft passes over a given geographical location is frequently expressed as the elapsed time between the northbound equator crossing (ascending node) and the time it reaches the particular location. In this way, time is considered zero when the spacecraft passes the equator northbound and increases through a complete orbital period.

The time required for a spacecraft to move through a given geocentric angle of its ellipse is considered to be constant fop. any particular day so that the time required for the spacecraft to reach a particular latitude is the same for every circuit of the earth on that day. For example, if it reaches latitude 30 degrees North ten minutes after the northbound equator crossing (ascending node) on one circuit of the earth, it will reach the same latitude (30 degrees N) at ten minutes after the ascending node on each succeeding circuit of the earth during that day. The movement of apogee and -perigee causes a very gradual change in the time necessary to reach this latitude on each circuit. These changes are included in the Daily Messages.

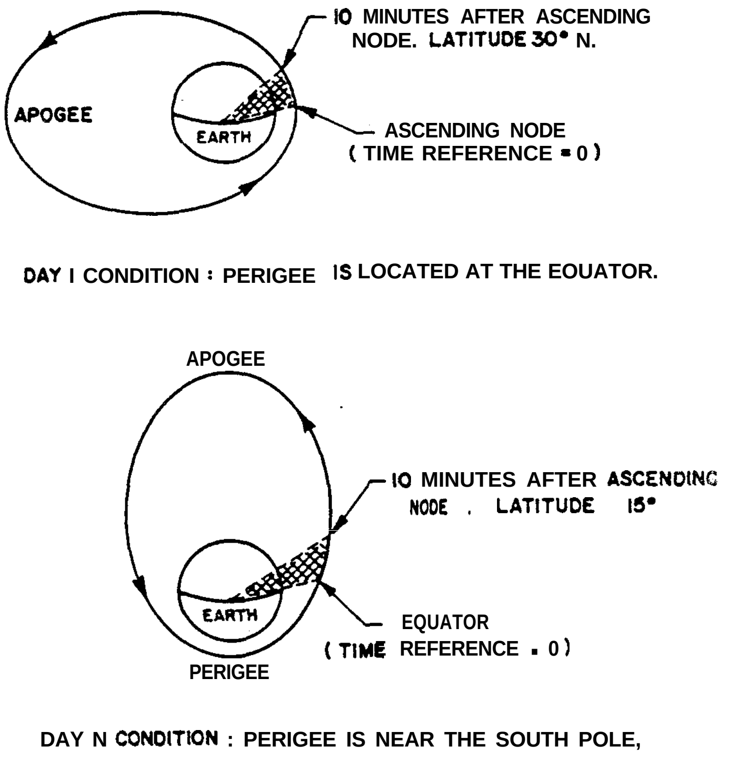


Figure 3-4 Diagram of Change in Perigee and Apogee

4. REAL-TIME DATA SYSTEMS FOR LOCAL USERS

Local users in line of sight of the TIROS-N satellite can receive real-time data directly from the' spacecraft. TIROS-N broadcasts visible (VIS) and IR data from the AVHRR as well as other data from the TIROS Operational Vertical Sounder (TOVS), the DCS, the SEM, and the spacecraft housekeeping telemetry. This section will focus on the direct readout imaging systems of TIROS-N.

4.1 APT System

The AVHRR provides the data for transmission to both the APT and HRPT users. The HRPT data are transmitted at full resolution (1.1 km), whereas the APT output is transmitted at reduced resolution (4 km) to maintain bandwidth constraints. The APT system transmits any two of the AVHRR channels (see Table 2-l); the visible channel is used to provide visible APT imagery during daylight, and one IR channel is'used constantly (both day and night). A second IR channel can be scheduled to replace the visible channel observations during the nighttime portions of the orbit.

4.2 HRPT System

The HRPT system transmits all of the channels. To avoid future changes on the spacecraft and on-ground receiving equipment, the TIROS-N HRPT data format has been designed as though the AVHRR were already a five-channel instrument. When operating with the initial four-channel instrument, the data from Channel 4 (11 μm) are inserted in the data stream twice so that the basic data format will be the same for both the four- and five-channel versions. output from the low data-rate system onboard the spacecraft is multiplexed with the AVHRR data and becomes a part of the HRPT output available to direct readout users. The low data-rate system includes the the instruments of the TOVS, the SEM, the DCS, and the spacecraft housekeeping telemetry.

4.3 Direct Sounder Broadcasts (DSB)

Data from the TOVS instruments are available from two separate real-time data transmission links. Onboard the satellite, the TOVS data are collected and formatted by the TIP. Parallel outputs are provided for:

- the real-time VHF beacon transmission link, and
- MIRP, which combines the TIP data with the output from the AVHRR. This combined data stream is:

  broadcast in real-time as the HRPT service and
  stored onboard the satellite for later transmission to the ground.

Note that all data from the TOVS are digital and that the data included within the HRPT format are identical to that broadcast on the beacon. Data from the TOVS are available on both very high frequency (VHF) and S-band data links. Those users receiving the high resolution transmission from the AVHRR (HRPT system) will probably find it most desirable to extract the TOVS data from this data stream. Using two frequencies for these data eliminates interference between transmissions from two satellites within view of a station. This problem is particularly severe in high latitudes where overlapping coverage is routine.

The VHF beacon data, also with two possible frequencies, are available for users who do not intend to install the more complex equipment necessary to receive data on the S-band frequencies. The lower data rates (8 kilobits/second versus 665.4 kilobits/second for HRPT) permit the user to install less complex and less costly equipment to receive the data without degrading its quality.

4.4 Data Collection System (DCS)

The Data Collection System (DCS) onboard TIROS-N is provided by CNES of France. This system, also referred to as the ARGOS Data Collection and Platform Location System (ARGOS DCLS), provides a means to locate and/or collect data from fixed and free floating buoy and balloon platforms_. It provides two new services not currently present in the geostationary satellite (GOES) data collection systems. First, it is able to determine platform location using an inverse doppler technique; second, it is able to acquire data from any place in the world, but particularly in the polar regions beyond transmission range of the geostationary satellites.

The ARGOS System will receive data from the platforms at UHF 401.65 megahertz (MHz) . The platforms will transmit independently of any interrogation from the spacecraft that uses a random access receiving system. Each platform will make continual transmissions, varying in length from 360 to 920 milliseconds (ms) and a repetition interval from 40 to 200 seconds. As the spacecraft passes within range of a platform during its orbit-, it will receive and record the successive transmissions. Once the spacecraft comes within range of a CDA, it will play back on command the recorded data to the ground facility. On the ground, the data will be forwarded to Suitland, where the ARGOS data will be'separated from the other spacecraft telemetry data and relayed to the CNES processing center in Toulouse France. There, the platform locations will be computed and the data processed and prepared for relay to the user. The location information is determined by measuring the platform carrier frequency received by the DCS instrument in the spacecraft at each transmission. When several transmissions are obtained from a particular platform, differential doppler techniques are used to determine the platform location within an accuracy of 3 to 5 km.

'With two spacecraft operating in the TIROS-N operational system, a platform will be in contact with the spacecraft during at least four intervals each day, about six hours apart. During any interval, the platform will be "seen" by the spacecraft on at least two successive orbits, which would provide a minimum of eight reports a day. In the polar areas, as the orbital paths converge, many more contacts will be made. Up to twenty or more reports may be acquired, approximating the frequency of coverage available through the geostationary satellites.

The ARGOS system will also provide for the immediate rebroadcast of data received from platforms. These data reports will be included in the same data stream that contains the direct broadcast of sounder data. The spacecraft VHF beacon transmits the DCS data at the low rate and the S-band beacon (HRPT) transmits the DCS data at the higher speed. Only data from platforms so located that both the platforms and the receive site are simultaneously in view of the satellite will be available from this direct broadcast. The DCS data in the direct broadcast will only permit platform location computations when a computer with the proper software is available for processing the data.

For more details on the ARGOS system contact Service ARGOS at the following address:

Service ARGOS
Centre Spatial de Toulouse
18, Avenue Edouard Belin
31055 Toulouse CEDEX
France

5. TRACKING PROCEDURES FOR DIRECTIONAL. ANTENNAS USED TO ACQUIRE DATA FROM REAL-TIME TRANSMISSIONS SYSTEM SENSORS

5.1 'Introduction

All operators of satellite stations designed to receive any type of direct readout transmissions from polar orbiting satellites need to know the satellite's position in time and space in order to know when to operate their equipment and to permit them to locate geographically the features seen in the images. Operators of stations using directional antennas also need this information to determine antenna pointing angles. Satellite tracking procedures are not required for receiving stations equipped with omnidirectional antennas.

The primary source of information concerning a satellite's position in time and space is the APT Predict bulletin. The information in the bulletin can be used with an APT plotting board and a tracking diagram to determine the antenna azimuth and elevation angles necessary to follow a polar orbiting satellite passing within receiving range of a given station. The content and primary sources of the APT Predict bulletin and the use of the plotting board and tracking diagram are described in Sections 5.2 through 5.6. Alternate sources and forms of satellite prediction information are identified in Section 5.7.

The code form of the APT Predict (TBUS) bulletin, an example of an actual TIROS-N TBUS bulletin, and a decoding exercise are given in Appendix A. Exercises in the application of the TBUS bulletin (Plotting Board preparation, tracking, and gridding) are given in Appendices B through D.

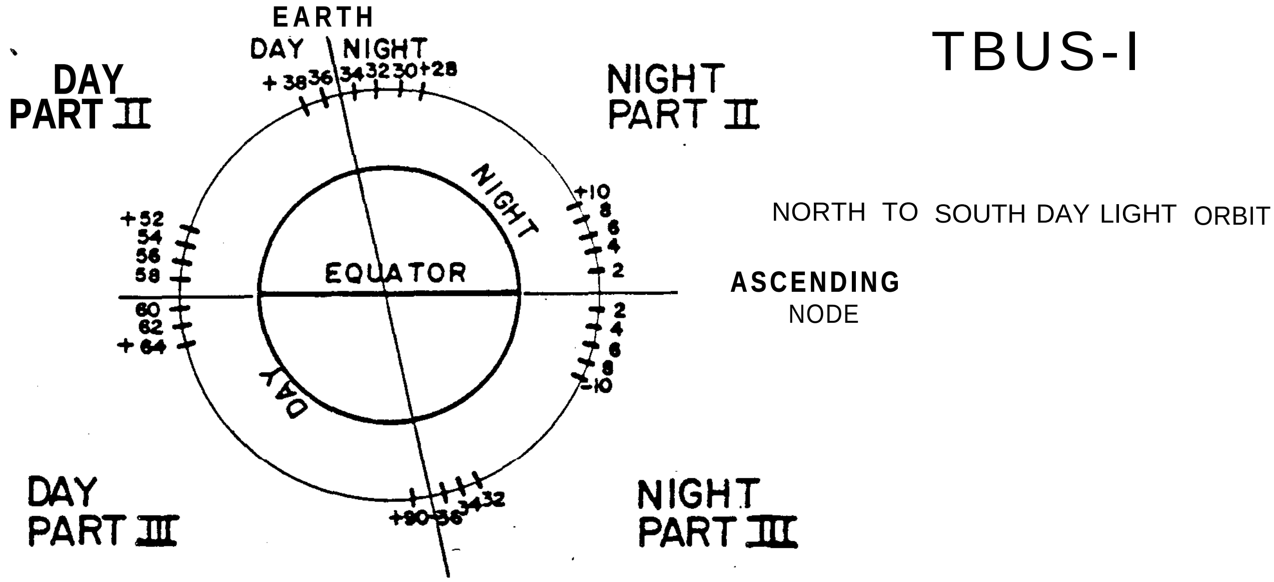
5.2 APT Predict (TBUS) Bulletin

The APT Predict (TBUS) bulletin contains information on satellite equator crossing times and longitudes, orbit numbers, orbital period, longitudinal time, and longitude increments between successive orbits; also, satellite positions at two-minute intervals (for a reference orbit), transmission frequencies, and other information related to satellite tracking and performance. The information identifies those orbits that will occur three days after the date of the bulletin (for example, information disseminated on the tenth of the month pertains to orbits that will occur on the thirteenth of the month).

The bulletins are prepared by NESS and transmitted through the National Weather Service Communications Center (KWBC) to major communications centers and relay points around the world. These transmissions occur daily, at about 1908 GMT, by landline and radio-teletype links to the World Weather Watch's Global Telecommunications Service (GTS). The GTS primarily serves the international meteorological community; therefore, most nonmeteorological services, academic and commercial institutions, and other organizations and individuals cannot receive the complete TBUS bulletins unless they have the proper receiving and printing devices and are able to intercept radio teletype broadcasts. Still, it is important for those who are not connected with this service to understand the derivation and content of the TBUS bulletin, because nearly all other orbital predict data are extracts from this message form:

There are two forms of the TBUS bulletin. One form, identified as TBUS-1, is used to convey information about satellites that are descending in daylight (traveling north-to-south on the sunlit portion of the orbit). The second form, TBUS-2, provides data for satellites ascending in daylight (northbound on the sunlit portion of the orbit). A schematic representation of the TBUS-1 and TBUS-2 bulletins is given in Figure 5-1.

Both bulletins consist of four parts. Part 1 is quite short. It identifies a reference orbit on a given day (three days after the date of the bulletin) and gives the equator crossing time and longitude for this reference orbit. This is followed by an orbital nodal period and a longitudinal increment-- the separation between successive equator crossings, measured in degrees. The orbit numbers of the fourth and eighth orbits following the referenced orbit are then listed along with the equator crossing times and longitude of these orbits..



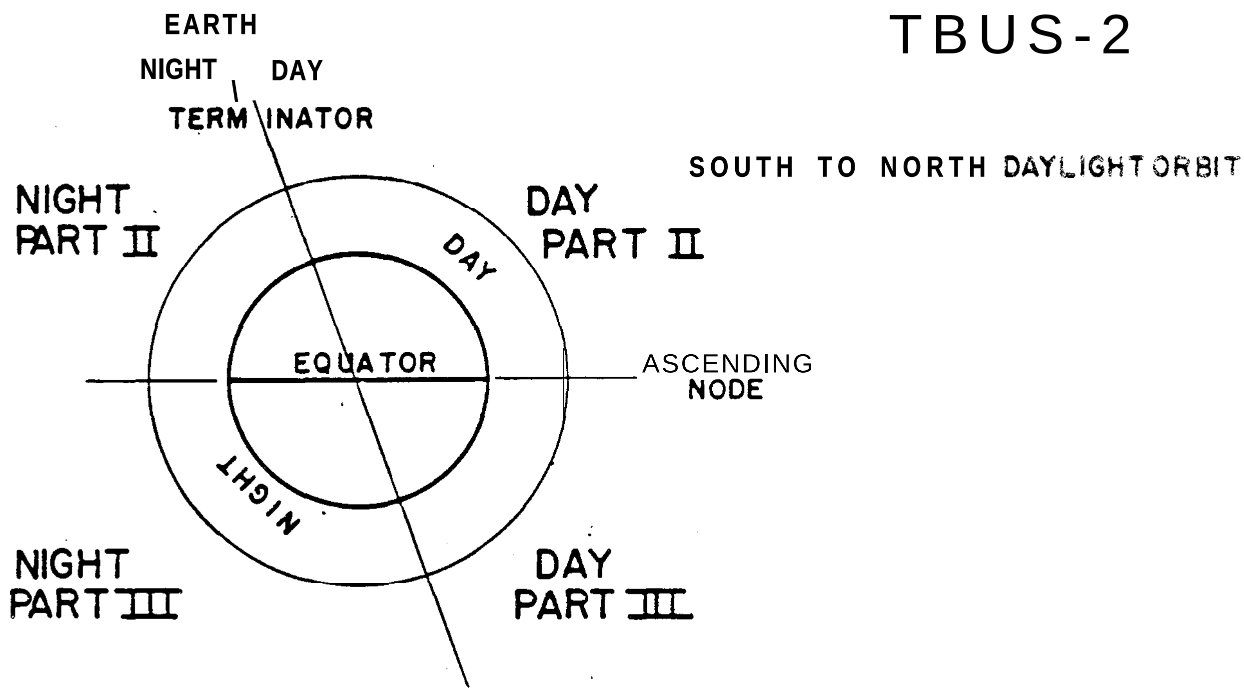


Figure 5-1 Schematic representation of information conveyed in TBUS-1 and TBUS-2 bulletins

By itself, Part I contains sufficient information to permit the user-to calculate future equator crossing times and longitudes several days in advance with considerable accuracy. During -periods of maximum solar activity, however, the accuracy of crossing times and longitudes extrapolated from Part I information diminishes if the extrapolations are carried much more than a week ahead.

Parts II and III of the bulletins are quite lengthy. Part II (Day) contains predicted subpoint and height data at two-minute intervals for the portion of the orbit that is sunlit north of the equator. Part II (Night) contains predicted subpoint and height data at two-minute intervals for the portion of the orbit in darkness north of the equator. Part III (Day) contains predicted subpoint and height data at two-minute intervals for the portion of the orbit that is sunlit south of the equator. Part III (Night) contains predicted subpoint and height data at two-minute intervals for the portion of the orbit in darkness south of the equator. All times are referenced to the ascending node (northbound equator crossing) and are given as minutes after or before this time as shown in Figure 5-1.

Part IV is relatively short, and usually consists of three items: a code group, transmission frequencies of each operating direct readout sensor system, and remarks. The code group contains the orbital parameters used to generate Parts I, II, and III. It is intended for use by those station operators needing more precision in satellite tracking and having appropriate computer programs to ingest such data to produce both equator crossings and antenna pointing angles.

Remarks in Part IV are in plain language and advise the ground station operator of problems or changes in the mode of operating the satellite. In particular, erratic behavior or failure of a sensor, transmitter, or spacecraft will be indicated under "Remarks." An example of an actual TIROS-N TBUS bulletin, the code form, and an exercise in decoding are given in Appendix A.

For NOAA-l through NOAA-5, NASA provided NESS with the orbital parameters on a weekly basis. For TIROS-N series spacecraft (such as TIROS-N and NOAA-6), the information is obtained on a daily basis from

United States Air Force NORAD stations; the NORAD stations determine the orbits and provide NESS with high-precision orbital elements on a daily basis, and low-precision orbital elements as needed (high-precision orbital elements are expected to provide an'in-orbit positioning accuracy of ± 3 km). The elements are used to provide a satellite ephemeris file, which is then accessed to produce the TBUS bulletin.

Transmission frequencies for each operating direct readout service (APT, HRPT, and DSB) also are included in Part IV. The APT will always operate on a frequency of either 137.50 or 137.62 MHz; the HRPT will transmit on 1698, 1702.5, or 1707 MHz (1702.5 MHz would be used for HRPT in the event of failure of primary transmitters); the DSB will operate on the (beacon) frequencies, either 137.77 MHz or 136.77 MHz. The selection of a particular frequency for any of these transmissions depends on whether other satellites in this same series are operating and the frequencies they are using. Another factor, of course, will be transmitter performance.

Channel selection for APT transmissions is shown in Part IV of the TBUS bulletin. The two-channel output of the APT is derived from the five-channel AVHRR on TIROS-N series spacecraft. Two of the five channels have responses in the visible region of the electromagnetic spectrum; the other three channels are in the IR region. Data from one visible and one IR channel will be transmitted continuously, both day and night. A second IR channel can be programmed to replace the visible channel data at night, however.

5.3 Plotting Board

The APT Plotting Board is a polar projection diagram of the ear centered at either pole and extended 30 degrees of latitude past th equator into the other hemisphere. (Examples of plotting boards for the Northern and Southern Hemispheres are shown in Figures 5-2 and 5-3, respectively.) The -Board has radials from the pole representing one-degree intervals of longitude; each fifth radial is accentuated. Concentric circles on the projection represent latitudes. The equatorial latitude (zero degrees) is represented by a

APT SYSTEM

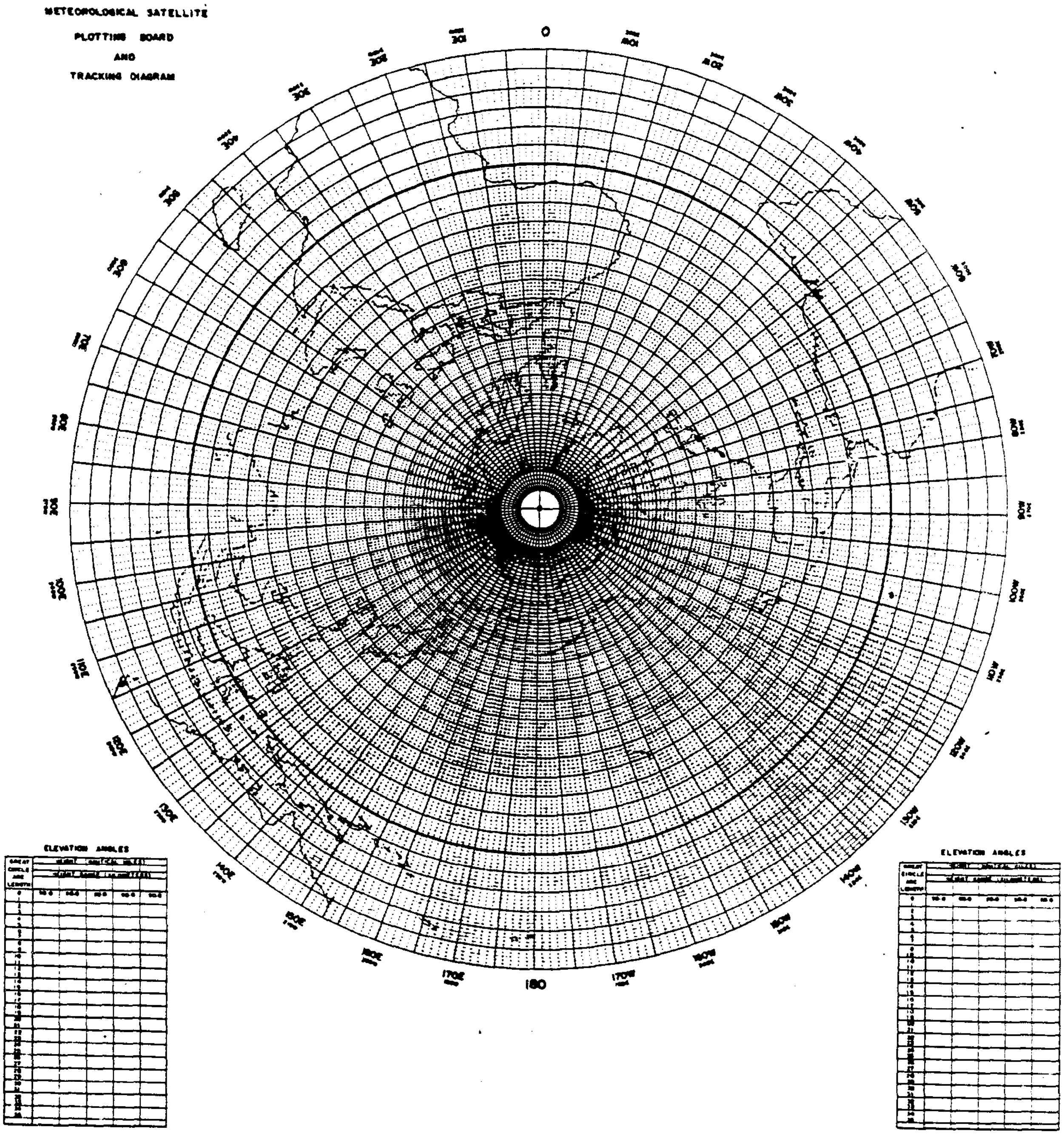


Figure 5-2 Plotting Board--Northern Hemisphere

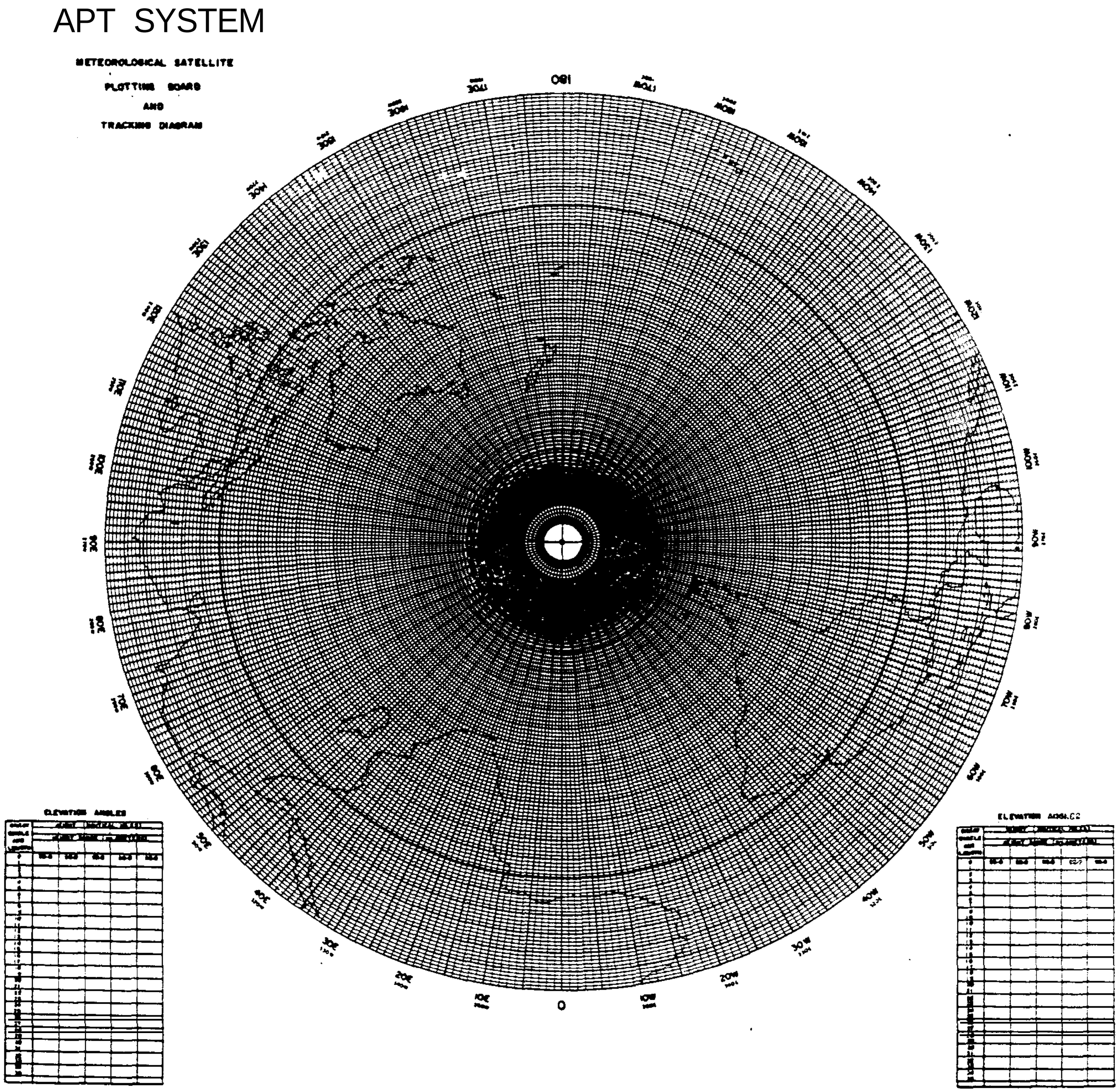


Figure 5-3 Plotting Board--Southern Hemisphere

heavier circle for clarity. A transparent overlay is centered at the pole on the Plotting Board. The subpoint track for the spacecraft from which data are to be acquired is plotted on this overlay. (An exercise in the preparation of the Plotting Board is given in Appendix B.)

5.4 Tracking Diagram

5.4.1 Theory of Determining Azimuth and Elevation

Azimuth is a function of the direction of the spacecraft from the antenna site and can be measured on any convenient map on which the station and spacecraft location can be plotted.

Spacecraft elevation angle is a function of the spatial location (position and height) of the spacecraft and the ground station antenna (see Figure 5-4). If the spacecraft altitude (h) and the distance from the ground station antenna to the spacecraft subpoint are known, the elevation angle (θ) of the spacecraft can be computed.

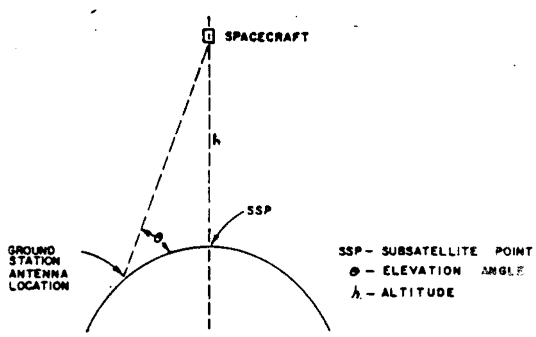


Figure 5-4 Diagram for Computing Spacecraft Elevation Angle

5.4.2 Application of Tracking Diagram

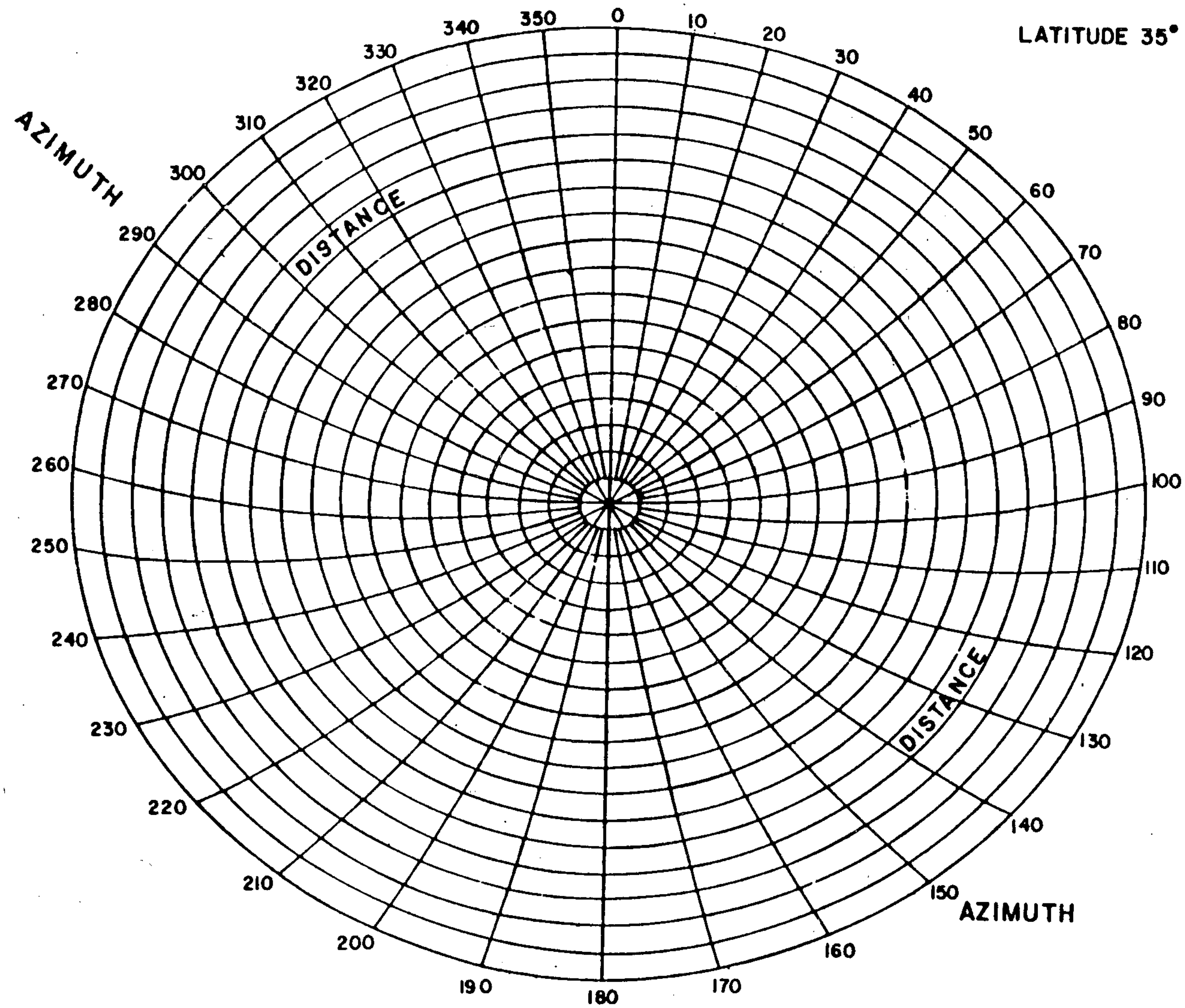
The tracking diagram (Figure 5-5) was designed for use with the Plotting Board and is constructed to show azimuth and distance of the spacecraft from the antenna site for a given subpoint position. The concentric curves (near ellipses) are isopleths of great circle arc distance drawn at two-degree 222 km (120 nmi) intervals.

Azimuth is used directly in tracking; arc distance (geocentric degrees) must be converted to elevation angle. Tables 5-1 and 5-2 provide a convenient conversion from arc length to elevation angle. Note here that the arc distance on the diagram can be converted to and labeled directly as elevation angles. This conversion is particularly desirable if a circular orbit is achieved because, when labeled, the diagram need not be changed during the lifetime of the spacecraft. An elliptical orbit requires frequent changes of labels so use of the tables is recommended in place of labeling.

A tracking diagram is available for each five-degree latitude belt. The diagram drawn for the latitude closest to the antenna location should be used because the scale changes significantly with latitude.

5.5 Clock

A station clock must be readily available when tracking (if a directional antenna is used) and when acquiring data. This clock should be accurate to one second and easily read if accurate data location is to result. Because the spacecraft moves over the earth at approximately 380 km (210 nmi) per minute, a one-second time error results in a location error of 6.5 km (3.5 nmi).



TRACKING DIAGRAM
AZIMUTH GREAT CIRCLE ARC LENGTH DIAGRAM
FOR LATITUDE 35 DEGREES

EACH ELLIPSE REPRESENTS A GREAT CIRCLE CENTERED AT THE STATION LOCATION (FOR THIS CASE NEAR 35 DEGREES LATITUDE).
INTERVAL OF ARC: 120 NAUTICAL MILES

Figure 5-5 Tracking Diagram

TABLE 5-1

GREAT CIRCLE ARC LENGTH AT ZERO-DEGREE ELEVATION

Orbit Height (nm)	Arc Length	Height (km)	Arc Length
100	13.6	200	14.2
125	15.2	250	15.8
150	16.6	300	17.3
175	17.9	350	18.6
200	19.1	400	19.8
225	20.2	450	20.9
250	21.2	500	22.0
275	22.2	550	23.0
300	23.1	600	23.9
325	24.0	650	24.9
350	24.8	700	25.7
375	25.6	750	26.5
400	26.4	800	27.3
425	27.1	850	28.1
450	27.8	900	28.8
475	28.5	950	29.5
500	29.2	1000	30.2
525	29.8	1050	30.9
550	30.4	1100	31.5
575	31.0	1150	32.1
600	31.6	1200	32.7
625	32.2	1250	33.3
650	32.7	1300	33.9
675	33.3	1350	34.4
700	33.8	1400	34.9
725	34.3	1450	35.5
750	34.8	1500	36.0
775	35.3	1550	36.5
800	35.8	1600	36.9
825	36.2	1650	37.4
850	36.7	1700	37.9
875	37.1	1750	38.3
900	37.6	1800	38.8

TABLE 5-2

ELEVATION ANGLE AS A FUNCTION OF GREAT CIRCLE ARC LENGTH AND ALTITUDE

Great Circle Arc Length

Altitude (nmi)	Altitude Range (km)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
200	348/393	90.0	71.5	57.9	44.2	37.3	30.7	25.5	21.4	18.1	15.3	12.9	10.9	9.1	7.4	6.0	4.6	3.4	2.2	1.1	0.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
225	394/439	90.0	73.3	60.8	49.4	40.6	33.7	28.3	24.0	20.5	17.5	15.0	12.7	10.8	9.0	7.5	6.0	4.7	3.5	2.3	1.2	0.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
250	440/486	90.0	74.8	63.2	52.2	43.5	36.5	31.0	26.4	22.8	19.6	16.9	14.5	12.5	10.6	8.9	7.4	6.0	4.7	3.5	2.3	1.2	0.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
275	487/432	90.0	76.0	65.1	54.7	46.1	39.1	33.4	28.8	24.9	21.6	18.8	16.3	14.1	12.2	10.4	8.8	7.3	5.9	4.6	3.4	2.3	1.2	0.2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
300	533/578	90.0	77.1	66.9	56.9	48.4	41.5	35.8	31.0	27.0	23.5	20.6	18.0	15.7	13.7	11.8	10.1	8.6	7.1	5.8	4.5	3.3	2.2	1.1	0.1	*	*	*	*	*	*	*	*	*	*	*	*	*
325	579/625	90.0	78.0	68.3	58.8	50.6	43.7	37.9	33.1	28.9	25.4	22.3	19.6	17.3	15.1	13.2	11.4	9.8	8.3	6.9	5.6	4.4	3.2	2.1	1.0	*	*	*	*	*	*	*	*	*	*	*	*	*
350	626/671	90.0	78.7	69.6	60.5	52.5	45.7	39.9	35.0	30.8	27.2	24.0	21.2	18.8	16.6	14.5	12.7	11.0	9.5	8.0	6.6	5.4	4.1	3.0	1.9	0.8	*	*	*	*	*	*	*	*	*	*	*	*
375	672/717	90.0	79.5	70.8	62.0	54.3	47.6	41.8	36.9	32.6	28.9	25.7	22.8	20.2	18.0	15.9	14.0	12.2	10.6	9.1	7.7	6.3	5.1	3.9	2.7	1.7	0.6	*	*	*	*	*	*	*	*	*	*	*
400	718/764	90.0	80.0	71.8	63.4	55.9	49.3	43.6	38.6	34.3	30.5	27.2	24.3	21.7	19.3	17.1	15.2	13.4	11.7	10.1	8.7	7.3	6.0	4.8	3.6	2.5	1.4	0.4	*	*	*	*	*	*	*	*	*	*
425	765/810	90.0	80.5	72.7	64.6	57.3	50.9	45.2	40.2	35.9	32.1	28.7	25.7	23.0	20.6	18.4	16.4	14.5	12.8	11.2	9.7	8.3	6.9	5.7	4.5	3.3	7.2	1.1	0.1	*	*	*	*	*	*	*	*	*
450	811/856	90.0	81.0	73.5	65.7	58.7	52.3	46.7	41.8	37.4	33.6	30.1	27.1	24.3	21.9	19.6	17.5	15.6	13.8	12.2	10.7	9.2	7.8	6.5	5.3	4.1	3.0	1.9	0.8	*	*	*	*	*	*	*	*	*
475	857/810	90.0	81.4	74.2	66.8	59.9	53.7	48.1	43.2	38.9	35.0	31.5	28.4	25.6	23.1	20.8	18.7	16.7	14.9	13.2	11.6	10.1	8.7	7.4	6.1	4.9	3.7	2.6	1.5	0.5	*	*	*	*	*	*	*	*
500	904/949	90.0	81.8	74.9	67.7	61.0	54.9	49.5	44.6	40.3	36.3	32.8	29.7	26.9	24.3	21.9	19.8	17.8	15.9	14.2	12.6	11.0	9.6	8.2	6.9	5.7	4.5	3.3	2.3	1.2	0.2	*	*	*	*	*	*	*
525	950/995	90.0	82.1	75.5	68.5	62.0	56.1	50.7	45.9	41.6	37.6	34.1	30.9	28.1	25.5	23.0	20.8	18.8	16.9	15.1	13.5	11.9	10.4	9.0	7.7	6.4	5.2	4.1	2.9	1.9	0.8	*	*	*	*	*	*	*
550	996/1,042	90.0	82.5	76.0	69.3	63.0	57.2	51.9	47.1	42.8	38.9	35.3	32.1	29.2	26.6	24.1	21.9	19.8	17.9	16.1	14.4	12.8	11.3	9.8	8.5	7.2	6.0	4.8	3.6	2.5	1.5	0.4	*	*	*	*	*	*
575	1,043/1,088	90.0	82.7	76.5	70.0	63.9	58.2	53.0	48.2	44.0	40.0	36.5	33.3	30.4	27.6	25.2	22.9	20.8	18.8	17.0	15.3	13.6	12.1	10.6	9.3	7.9	6.7	5.5	4.3	3.2	2.1	1.1	*	*	*	*	*	*
600	1,0[illegible]/1,134	90.0	83.0	77.0	70.7	64.9	59.1	54.0	49.0	45.1	41.2	37.6	34.4	31.4	28.7	26.2	23.9	21.7	19.7	17.9	16.1	14.5	12.9	11.4	10.0	8.7	7.4	6.2	5.0	3.8	2.7	1.7	*	*	*	*	*	*
625	1,135/1,181	90.0	83.2	77.4	71.3	65.5	60.0	55.0	50.4	46.1	42.2	38.7	35.5	32.5	29.7	27.2	24.8	22.7	20.6	18.8	17.0	15.3	13.7	12.2	10.8	9.4	8.1	6.8	5.6	4.5	3.3	2.3	1.2	0.2	*	*	*	*
650	1,182/1,227	90.0	83.5	77.8	71.9	66.2	60.9	55.9	51.3	47.1	43.3	39.7	36.5	33.5	30.7	28.2	25.8	23.6	21.5	19.6	17.8	16.1	14.5	13.0	11.0	10.1	8.8	7.5	6.3	5.1	4.0	2.8	1.8	0.7	*	*	*	*
675	1,228/1,273	90.0	83.7	78.2	72.4	66.9	61.7	56.8	52.3	48.1	44.2	40.7	37.5	34.4	31.7	29.1	26.7	24.5	22.4	20.5	18.6	16.9	15.2	13.7	12.2	10.8	9.4	8.2	6.9	5.7	4.6	3.4	2.3	1.3	0.3	*	*	*
700	1,274/1,320	90.0	83.8	78.6	72.9	67.5	62.4	57.6	53.1	49.0	45.2	41.7	38.4	35.4	32.6	30.0	27.6	25.4	23.2	21.3	19.4	17.7	16.0	14.4	12.9	11.5	10.1	8.8	7.5	6.3	5.1	4.0	2.9	1.8	0.8	*	*	*
725	1,321/1,366	90.0	84.0	78.9	73.4	68.1	63.1	58.3	49.9	46.1	42.6	39.3	36.3	33.5	30.9	28.5	26.2	24.1	22.1	20.2	18.6	16.7	15.1	13.6	12.2	10.8	9.4	8.2	6.9	5.7	4.6	3.5	2.4	1.3	0.3	*	*	*
750	1,367/1,413	90.0	84.2	79.2	73.8	68.6	63.7	59.1	54.8	50.7	46.9	43.3	40.2	37.1	34.3	31.8	29.3	27.0	24.9	22.8	21.0	19.2	17.4	15.8	14.3	12.8	11.4	10.1	8.8	7.5	6.3	5.1	4.0	2.9	1.9	0.8	*	*
775	1,414/1,459	90.0	84.3	79.4	74.2	69.1	64.3	59.8	55.5	51.5	47.7	44.3	41.0	38.0	35.2	32.6	30.1	27.8	25.7	23.6	21.7	19.9	18.2	16.5	15.0	13.5	12.0	10.7	9.4	8.1	6.9	5.7	4.5	3.4	2.4	1.3	0.3	*
800	1,460/1,505	90.0	84.5	79.7	74.6	69.7	64.9	60.4	56.2	52.3	48.5	45.1	41.8	38.8	36.0	33.4	30.9	28.6	26.4	24.4	22.4	20.6	18.8	17.2	15.6	14.1	12.7	11.3	10.0	8.7	7.4	6.2	5.1	4.0	2.9	1.8	0.8	*
825	1,506/1,551	90.0	84.6	80.0	75.0	70.1	65.5	61.1	56.9	53.0	49.3	45.8	42.6	39.6	36.8	34.7	31.7	29.3	27.2	25.1	23.2	21.3	19.5	17.9	16.3	14.7	13.3	11.9	10.5	9.2	8.0	6.8	5.6	4.5	3.4	2.3	1.3	0.2
850	1,552/1,598	90.0	84.8	80.2	75.3	70.5	66.0	61.7	57.5	53.7	50.0	46.6	43.4	40.4	37.5	34.9	32.4	30.1	27.9	25.8	23.8	22.0	20.2	18.5	16.9	15.4	13.9	12.5	11.1	9.8	8.5	7.3	6.1	5.0	3.9	2.8	1.7	0.7
875	1,599/1,644	90.0	84.9	80.4	75.6	71.0	66.5	62.2	58.2	55.0	51.4	48.0	44.8	41.8	39.0	36.3	33.9	31.5	29.3	27.2	25.2	23.3	21.5	19.8	18.1	16.6	15.1	13.6	12.2	10.9	9.6	8.4	7.1	6.0	4.8	3.7	2.6	1.6
900	1,645/1,690	90.0	85.0	80.6	75.9	71.4	67.0	62.8	58.7	55.0	51.4	48.0	44.8	41.8	39.0	36.3	33.9	31.5	29.3	27.2	25.2	23.3	21.5	19.8	18.1	16.6	15.1	13.6	12.2	10.9	9.6	8.4	7.1	6.0	4.8	3.7	2.6	1.6
925	1,691/1,736	90.0	85.1	80.8	76.2	71.7	67.4	63.3	59.3	56.6	52.0	48.6	45.5	42.5	39.7	37.0	34.5	32.2	30.0	27.8	25.8	23.9	22.1	20.4	18.7	17.2	15.6	14.2	12.8	11.4	10.1	8.9	7.6	6.5	5.3	4.2	3.1	2.0
950	1,737/1,783	90.0	85.2	81.0	76.5	72.1	67.9	63.8	59.9	56.1	52.6	49.3	46.1	43.2	40.4	37.7	35.2	32.8	30.6	28.5	26.5	24.6	22.7	21.0	19.3	17.7	16.2	14.7	13.3	11.9	10.6	9.4	8.1	6.9	5.8	4.6	3.5	2.5
975	1,784/1,829	90.0	85.3	81.2	76.7	72.5	68.3	64.2	60.4	56.7	53.2	49.9	46.8	43.8	41.0	38.4	35.9	33.7	31.3	29.1	27.1	25.2	23.2	21.6	19.9	18.3	16.8	15.3	13.8	12.5	11.1	9.9	8.6	7.4	6.2	5.1	4.0	2.9
1000	1,830/1,875	90.0	85.4	81.4	77.0	72.8	68.7	64.7	60.9	[illegible]	[illegible]	[illegible]	44.5	[illegible]	41.6	49.0	36.5	34.1	31.9	29.7	27.7	25.6	23.9	22.2	20.5	18.9	17.3	15.8	14.4	13.0	11.6	10.3	9.1	7.9	6.7	5.5	4.4	3.3

5.6 Tracking Procedures

The procedures for satellite tracking are described in the following sections. A tracking exercise, with all procedures explained in detail, is given in Appendix C.

5.6.1 Initial Preparation

Center the appropriate tracking diagram on the Plotting Board at the location (latitude and longitude) of the antenna site. The zero-degree azimuth line must always point toward the pole and the 0-180 radial must be parallel to a longitude line.

NOTE: Southern Hemisphere stations must relabel azimuth lines after the diagram is in place so that the zero-degree azimuth refers to North.

5.6.2 Post Launch Preliminary Preparation

Transparent Orbital Overlay

- Plot the orbital path on the Plotting Board overlay using the data in the first valid TBUS bulletin. Subdivide the track into one-minute intervals starting with minute zero at the equator. All points, therefore, will be plotted at a time relative to the ascending node (northbound equator crossing). Stations with the capability of receiving and displaying both day and night transmissions should plot the orbital subpoint track for both times of day as indicated in the Daily Message.
- Subdivide the equatorial line (on the orbital overlay) into divisions equal to the nodal increment. Begin at the reference orbit and progress westward through 360 degrees numbering sequentially from the reference orbit. Because the equator crossing for every fourth orbit is given in

Part I of the bulletin, with the reference orbit set properly, these points may be plotted directly to eliminate possible error.

Equator Line on Plotting Board

Determine and indicate on the equator line of the Plotting Board the acquisition zone of equator crossings (ascending nodes) that willbring the spacecraft within range of the antenna site. There will be two zones--one for the sunlit portion of the orbit and one for the night portion. These zones should be labeled appropriately.

- From the data in Table 5-1, determine the arc distance for a zero-degree antenna elevation when the spacecraft is at apogee (this distance provides an estimate of the maximum range from which data acquisition is possible).
- Indicate the zero degree line directly on the tracking diagram.
- Rotate the previously plotted orbital overlay diagram until the subpoint track (for the portion of the orbit where the spacecraft is heading northward) until it is tangent to the zero-degree elevation circle east of the antenna site. Indicate the longitude of the equator crossing (ascending node) of the plotted subpoint track. Rotate the orbital overlay until the subpoint track is tangent to the zero-degree elevation circle west of the antenna site. Again, determine longitude of the equator crossing (ascending node). Orbits whose ascending nodes fall between the two longitudes determined are (assuming no local obstruction) generally within line of sight of the spacecraft during the northward portion of these orbits.
- Repeat the process (b) for the portion of the orbit where the spacecraft is headed southward to determine the corresponding longitudinal range for southbound acquisition.

For practical application, the elevation of the spacecraft will have to exceed zero to five degrees above the horizon for at least four to five minutes during a pass before useful data can be expected. Exact limits can be determined by experience, and the longitudinal belts can be adjusted accordingly.

5.6.3 Daily Preparation--Derivation of Tracking Data

- Determine from the TBUS bulletin the exact equator crossing (longitude and time) of the orbits from which data are to be acquired.
- Place the ascending node of the plotted subpoint track overlay for the Plotting Board at the longitude of the ascending node of the reference orbit.
- Read directly the longitude of the ascending nodes and the number of orbital increments from the reference orbit to the equator crossings within the acquisition zone determined in the previous section.

Mathematically determine the equator crossing time of those orbits from which data are to be acquired by adding the proper number (as determined above) of nodal periods (TBUS bulletin) to the equator crossing time of the reference orbit. The exact longitude of the equator crossings may be determined similarly if desired. For most purposes, however, the graphical solution will prove to be of sufficient accuracy.

- Rotate the transparent orbital overlay until the ascending node of the plotted subpoint track is at the exact longitude of the orbit from which data are to be acquired.
- Read directly the azimuth and arc distance of the satellite (from the station) at the plotted points (one-minute intervals) along the track when the track is within the zero-degree elevation circle. The point of maximum elevation angle (minimum arc distance) may be included as a supplementary datum point.

- Convert arc distance to elevation angle (Table 5-2).
- Convert the time for each minute (which is relative to the equator crossing time) to Greenwich Mean Time (GMT).
- Check the accuracy of the clock. Set it to be accurate to within one second.

Note that when a relatively circular orbit is achieved and absolute pointing accuracy is not required, antenna predictions (with time relative to the equator crossing) may be reused for future orbits with similar equator crossing longitudes. It has been found for instance that it is entirely feasible to use a single antenna prediction for satellite equator crossings within 1 degree of the nominal predict. GMT (clock) time must be updated for the actual equator crossing time as determined from the daily message.

5.6.4 Tracking--Step Tracking

Because most receiving antennas will have beam widths of 20 to 30 degrees, the antenna must only move at one-minute intervals rather than track continuously. It is necessary, therefore, to keep as close to the predetermined values as possible; if, for instance, the computed values were:

Time	Azimuth	Elevation
15:50:25Z	150°	10°
15:51:25Z	140°	18°

The antenna should be pointed at 18 degrees elevation, 140 degrees azimuth at 15:50:55Z so that the antenna would be "ahead of" the satellite for 30 seconds and "behind" for a similar period. The next adjustment would then be at 15:51:55Z. When the elevation angle exceeds 50 degrees, the user may find that the antenna position must be changed at 30-second intervals, because azimuth will be changing rapidly during this period.

5.7 Alternate Sources and Forms of Satellite Prediction Position Information

The primary source of orbital prediction information for TIROS-N series satellites is the Global Telecommunications System (GTS), and the main form of this information is the TBUS bulletin. Many APT station operators, and some government agencies, do not have access to the GTS and must be able to obtain orbital prediction information from other sources. These alternate sources include, but are not limited to, the Aeronautical Fixed Telecommunications Network (AFTN), WEFAX broadcasts from U.S. geostationary satellites, radio/CW broadcasts, and mail.

5.7.1 Aeronautical Fixed Telecommunications Network

The AFTN primarily serves world-wide aviation interests. Satellite orbital prediction information is transmitted on the AFTN as an addressed message to those overseas agencies that cannot receive TBUS bulletins via the GTS.

Message traffic on the AFTN is limited to 200 five-word groups, and for this reason, only Part I and Part IV of the Predict bulletin are transmitted via this network.

5.7.2 WEFAX

The complete TBUS bulletin, except the Remarks portion of Part IV, is sent via GOES WEFAX once each day. Obviously, only those stations having both an APT and WEFAX receiving capability would need to, or be able to, copy these WEFAX broadcasts.

The format of this bulletin is described in Section 5.2 and in Appendix A. It is the same format used to transmit APT Predict (TBUS) bulletins via the GTS network.

5.7.3 Radio/CW/Teletype

The American Radio Relay League (ARRL), a nonprofit organization serving the amateur radio community, broadcasts satellite equator crossing times and longitudes daily via radio (voice), CW, and radio-teletype. These broadcasts contain crossing information only for satellite passes over the North American continent and can only be received in northern and eastern areas.

For additional information on broadcast times and frequencies, write to:

American Radio Relay League
225 Main Street
Newington, CT 06111

5.7.4 Mail

Many nongovernment satellite readout stations are unable to receive satellite orbital prediction information via government telecommunications networks. Others do not have the equipment to receive, or are not within range of U.S. geostationary satellites that broadcast the TBUS messages. In these instances, the only source of prediction data is a monthly letter prepared and distributed by NESS.

This information appears in the following form:

June 1, 1979

PREDICT DATA

for calculating satellite equator crossing times and longitudes:

	Reference Orbit Information				
Satellite	Orbit No.	Date/Time	Longitude (Ascending Node)	Nodal Period	Increment Between Orbit
TIROS-N	3252	01 June 0109.24	150.28	102.0949	25.52

Other Methods

In Africa, a number of countries receive orbital prediction information through Agency Pour la Seceirite de la Navigation Ericanne (ASECNA).

With the proper receiving equipment and teleprinter, some station operators are able to intercept the GTS radio-teletype transmissions of TBUS messages. Most major communications centers on the GTS (such as Offenbach and New Delhi) relay this information via landline and radio-teletype. Frequencies and schedules would have to be obtained from the center nearest to the station. In the area of the United Kingdom, it is known that this information is transmitted by station GFL, which operates on frequencies of 4489, 9886.5, and 14356 KHz 24 hours per day, and on 6835 KHz between 1800 and 0600Z.

As a general rule, satellite readout station operators who do not have access to the GTS, AFTN, WEFAX, or other such sources of predict data are urged to contact an office of their national meteorological agency or service to see if arrangements can be made to obtain copies of these messages. (This is not possible in the United States, because very few weather stations are linked to the GTS.)

Note that APT ground station operators who do not have a requirement to grid images can use any of the above sources of orbital information to predict the passage of satellites over their region. Operators of APT, HRPT, or other types of direct readout ground stations that require precise orbital information for tracking and/or gridding would need to receive orbital information via the GTS, AFTN, or geostationary satellites.

6. GEOGRAPHIC REFERENCING TECHNIQUES

This section provides a detailed discussion of techniques for the geographic referencing of the TIROS-N AVHRR continuous line scan data system. In this discussion, it is assumed that spacecraft roll, pitch, and yaw are all zero. Under these conditions, the scan is perpendicular to the heading line and contains the instantaneous subpoint at the bisector of the data line between earth horizons. Thus, the subpoint track can be represented by a straight line connecting the midpoint of each line.

6.1 Grid Format

A geographic referencing grid for the APT data transmitted by the TIROS-N series satellites has been prepared and is available to APT users on film. To fit the line-scan display on the ground, the grid must be enlarged to the size of the image. The grid can be obtained by contacting the Coordinator, Direct Readout Services.

A reproduction of the TIROS-N grid for an 840-km orbital height (sun-synchronous orbit, inclination 98.8 degrees) is shown in Figure 6-1. The solid line through the center, parallel to the edges, represents the subpoint track. Image edges are indicated by solid lines parallel to and at equal distances from the subpoint track. With correct orientation, a single grid drawn for one-quarter of the orbit may be used throughout the orbit. Orientation is proper for the orbital segment for which the legend may be read directly. Two copies of the grid may be combined (if desired by the user) to provide a continuous grid from pole to pole.

6.2 Grid Labels

Latitude lines are labeled directly on the grid, whereas the longitude lines are universal. The user assigns the proper longitude labels to conform with orbital data computed from the Daily Predict Bulletin. Latitude lines are drawn and labeled for five-degree

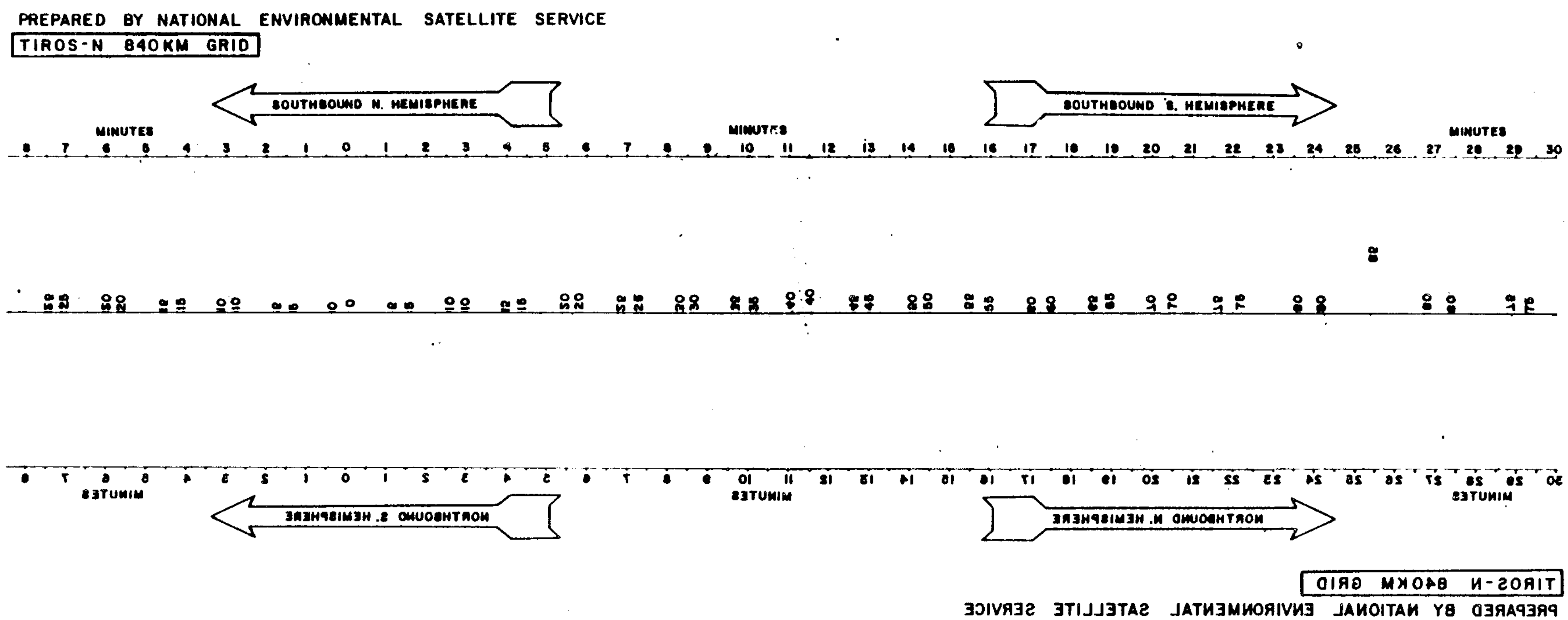


Figure 6-1 A Reproduction of the TIROS-N Grid for an 840-km Orbital Height.

intervals. Longitude interval is a function of latitude, with a spacing of five degrees from the equator to 50 degrees north or south, 10 degrees between 50 and 70 degrees, and 20 degrees from 70 to 85 degrees. Longitudes are not indicated above 85 degrees.

When assigning correct labels to the longitudes, the grid must be positioned so that the grid and image edges match and the individual lines of data are at their proper latitudinal position.. It is incorrect to move the grid perpendicular to the track so that longitude values coincide with the grid lines.

Two techniques are available for labeling longitude lines.

- Determine the longitude of the ascending (descending) node mathematically from information in the daily message and label this intersection directly on the grid. Other longitude lines should be labeled relative to this point.
- Determine the actual latitude and longitude of the subsatellite point for several lines of data during acquisition. Label the grid to conform to these points during the gridding procedure.

If an overlay type grid is used for geographical orientation of the APT data, the first technique will probably be the one most readily adaptable to image gridding. The grid may be prepared before data acquisition. If a projection method is used for gridding, the second technique will be most readily adaptable.

6.3 Fitting Grids to APT Images (Overlay Technique)

The following procedure is suggested for fitting grids to APT images using the overlay technique. A practical exercise in grid fitting is given in Appendix D. The exercise procedures, based on an earlier satellite grid, will be the same for the TIROS-N grid.

1) Preparation:
   a) determine subpoint data (latitude and height) directly from the daily message and extrapolate the ascending (descending) node longitude for the orbits from which data are to be acquired,

b) choose the 840-km height grid (already magnified to the correct size),

c) label the longitudes to conform to the ascending (descending) node determined in Step 1a, and

d) sketch the even five-degree intervals for convenience in using the data.

2) Determine time of receipt of several lines of data separated by 4 to 6 minutes. For convenience, use a time after (before) ascending node found in the daily message (example: 23 minutes after ascending node).

3) Determine directly latitude of subsatellite point at each of the times in Step 2.

4) Orient the grid properly (based on direction of spacecraft movement) and place it on the image so that the edges (grid and image) match and the latitudes of the subsatellite points, determined in Step 3, are correctly located.

6.4 Fitting Grids to Images (Projection Technique)

1) Determine subpoint data (latitude, longitude, and height) for the orbit on which data are to be acquired.

2) Determine time of receipt of several lines of data separated in time by 4 to 6 minutes. For convenience, those lines of data should be found which are acquired at an even minute interval after (before) the ascending node (use a minute value found in the daily message).

3) Determine the subsatellite point position of each line of data for which time was determined.

4) Enlarge the TIROS-N grid to the size of the image display.

5) Orient the grid properly to agree with the direction of motion of the spacecraft.

6) Project the grid onto the image so that the edges (grid and image) match and the latitude of the subsatellite points (Step 3) are correctly displayed.

7) Assign longitude values to agree with the data determined in Step 3. When using either of these techniques, landmarks should be checked to ensure a proper fit. Near the center of the grid, landmarks should appear in the correct location; if they do not, the grid should be adjusted to correct the errors. The most common causes of erroneous grid-fit are miscomputations, time, or attitude errors.

7. FORMAT OF DIRECT READOUT DATA

Examples of TIROS-N APT and HRPT direct readout images are shown in the following sections. These images are included in the User's Guide to demonstrate the format of the direct readout data transmitted by the TIROS-N series satellites and to demonstrate the differences between the APT and the HRPT images.

In some of the examples shown, the data have been processed to enhance certain features in the images. Although sophisticated types of data enhancement require expensive processing equipment, some enhancement of APT data can be performed using relatively inexpensive equipment available to APT users. For further information on techniques and equipment for image enhancement, it is suggested that the user contact the Coordinator, Direct Readout Services or contact directly the APT equipment manufacturers.

In the example images shown in the following sections, certain features of interest are pointed out. However, it is not the purpose of this User's Guide to present a complete discussion of the meteorological interpretation of direct readout data. References on data interpretation and analysis are given in the bibliography.

7.1 APT Data

An example of unenhanced APT data is shown in Figure 7-1. These data were received and recorded from the TIROS-N satellite on an afternoon ascending pass using an Alden APTS-3B Satellite Ground Receiving Station equipped with VHF omni-directional antenna (Model 9330-9-2A). The image on the left is Channel 4 (thermal infrared, 10.5-11.5 μm) and on the right Channel 1 (visible, 0.55-0.90 μm). It should be noted that these images have been inverted to facilitate interpretation of the data (north is at the top of the page). These images cover the eastern part of North America; Hudson Bay is near the top of the image, and Hispaniola can be identified near the bottom of the image.

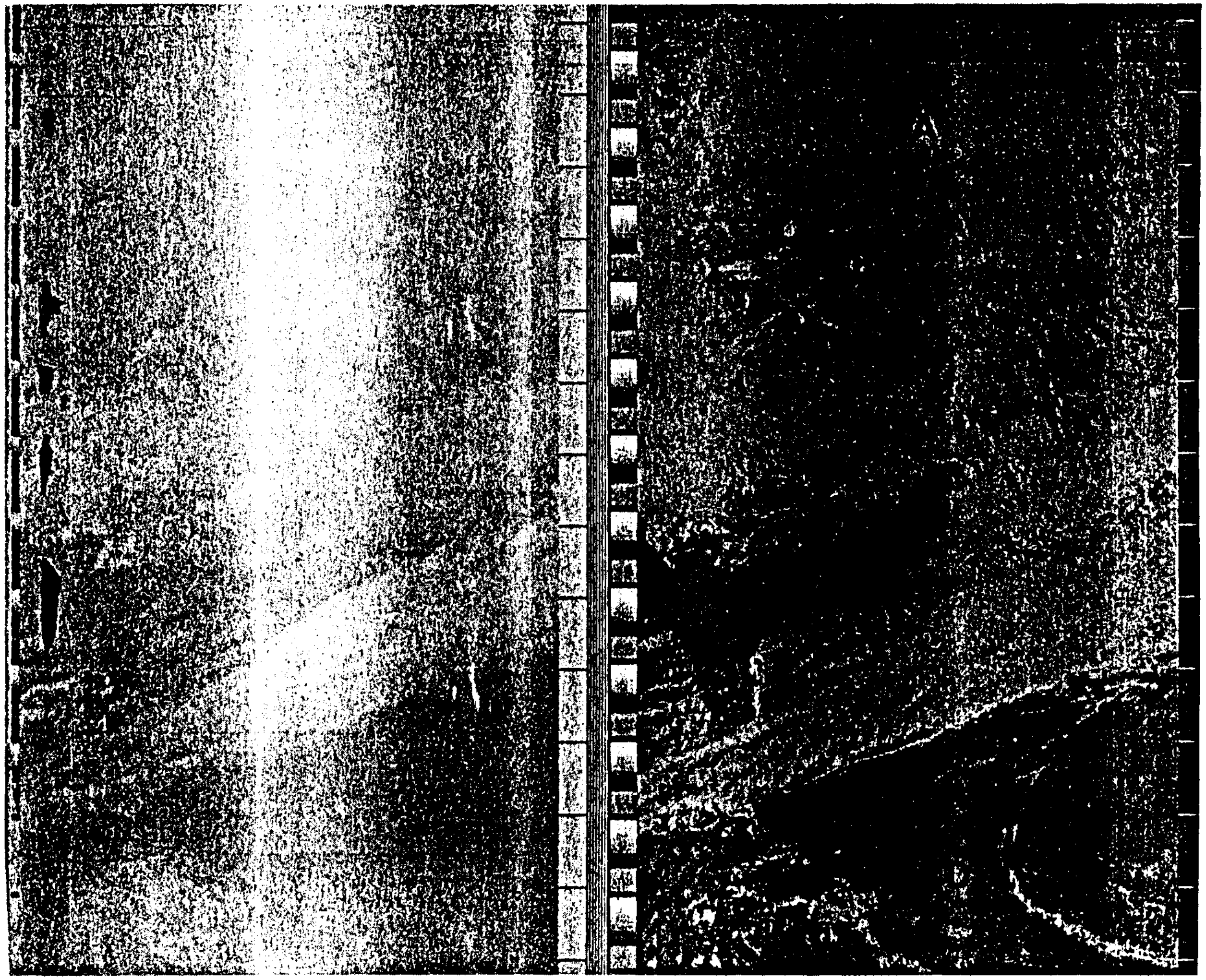


Figure 7-1 TIROS-N APT imagery. Channel 4 (thermal infrared, 10.5 - 11.5 μm) image is on the left (a), and Channel 1 (visible, 0.55 - 0.90 μm) image is on the right (b). Features that can be seen are: (A) Hudson Bay; (B) Great Lakes; (C) Florida; (D) Hispaniola; and (E) edge of snowline.

The channel identification on APT images may be accomplished by referring to the gray-scale wedge included along the edge of each image. The identification technique requires a visual comparison of the gray-level density of the "channel ID" step with the remaining eight steps. The step that matches the density of the channel ID step is the channel number.

Enhanced APT images are shown in Figure 7-2a (Channel 1) and Figure 7-2b (Channel 4). These enhanced images were processed from a tape recording of the same TIROS-N pass using a Leonessa Engineering K 300-140B signal processor. In the enhanced images, considerably greater detail can be seen than in the images processed with no enhancement. In the Channel 1 data (Figure 7-2a), for example, a distinct snowline can be seen extending southwestward from the southern end of Chesapeake Bay on the United States east coast. In the enhanced Channel 4 data (Figure 7-2b), clouds over the snow-covered ground can be more easily seen because of their lower temperatures; also, variations in sea surface temperature associated with the Gulf Stream can be detected off the east coast.

The thermal infrared image (Channel 4) provides a good illustration of the enhancement technique. In the data as received directly from the satellite, a full range of temperature is displayed in a limited number of gray-scale steps. It is difficult, therefore, to detect the subtle temperature differences in the display. In the enhanced data, the relationship between the temperature and the gray-scale levels can be varied. For example, the higher temperatures can be displayed in a greater number of gray-scale steps than in the original data (note the difference in the corresponding gray-scale wedges in Figures 7-1 and 7-2b). In this way, the subtle temperature differences can be displayed.

Examples of the other TIROS-N channels are shown in Figures 7-3 and 7-4. In Figure 7-3, Channel 2 (0.725-1.1 µm) is on the left and Channel 1 on the right. In this view of the central United States, greater contrast between water (lakes, rivers) and land can be seen in the Channel 2 image. In Figure 7-4, Channel 3 (3.55-3.93 µm) is on

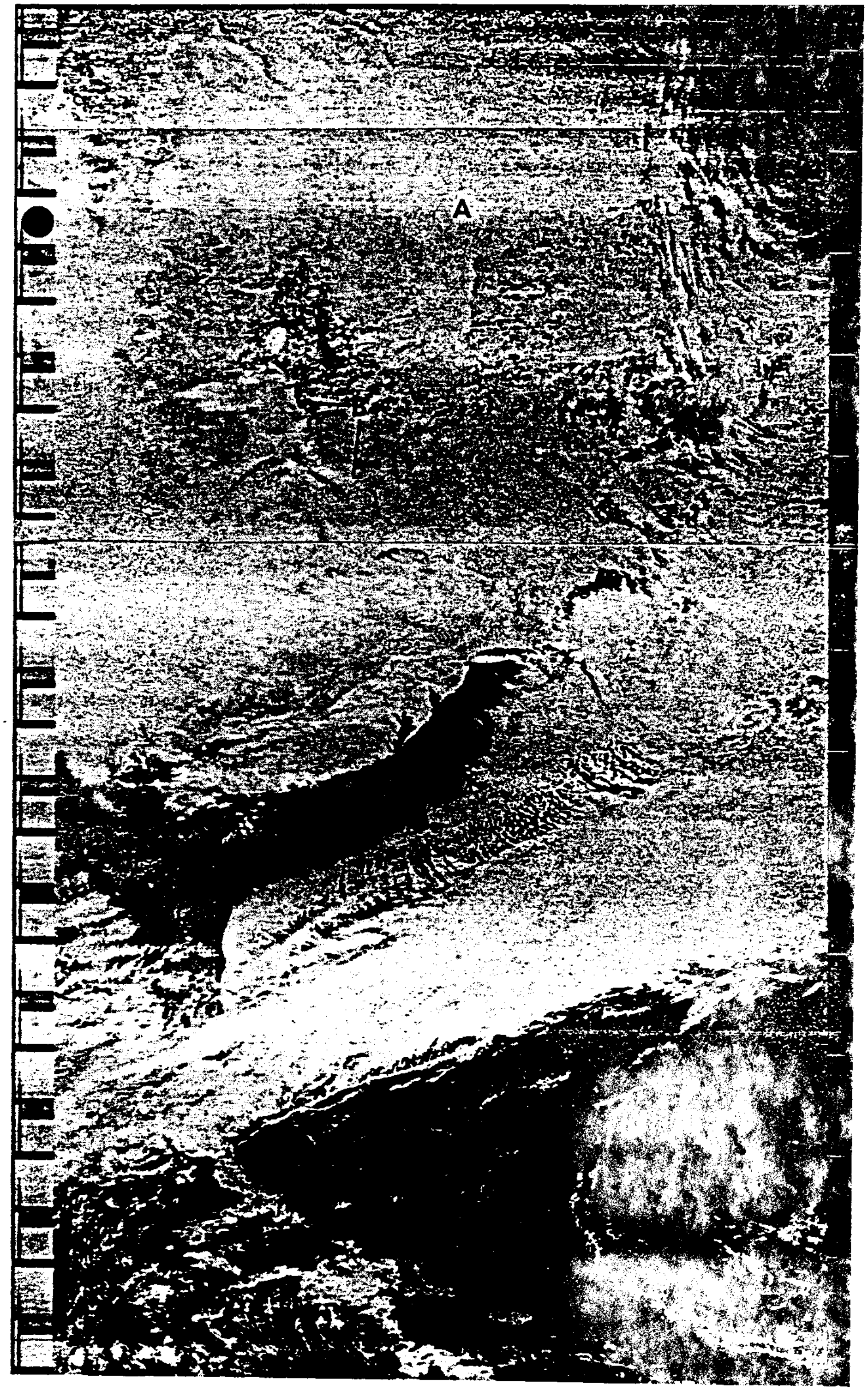


Figure 7-2a TIROS-N enhanced Channel 1 (visible) APT image of the eastern United States and the Atlantic Ocean. The snowline is much easier to discern as compared to the unenhanced Channel 1 image shown in Figure 7-1 (b). Refer to Figure 7-1 for identification of features.

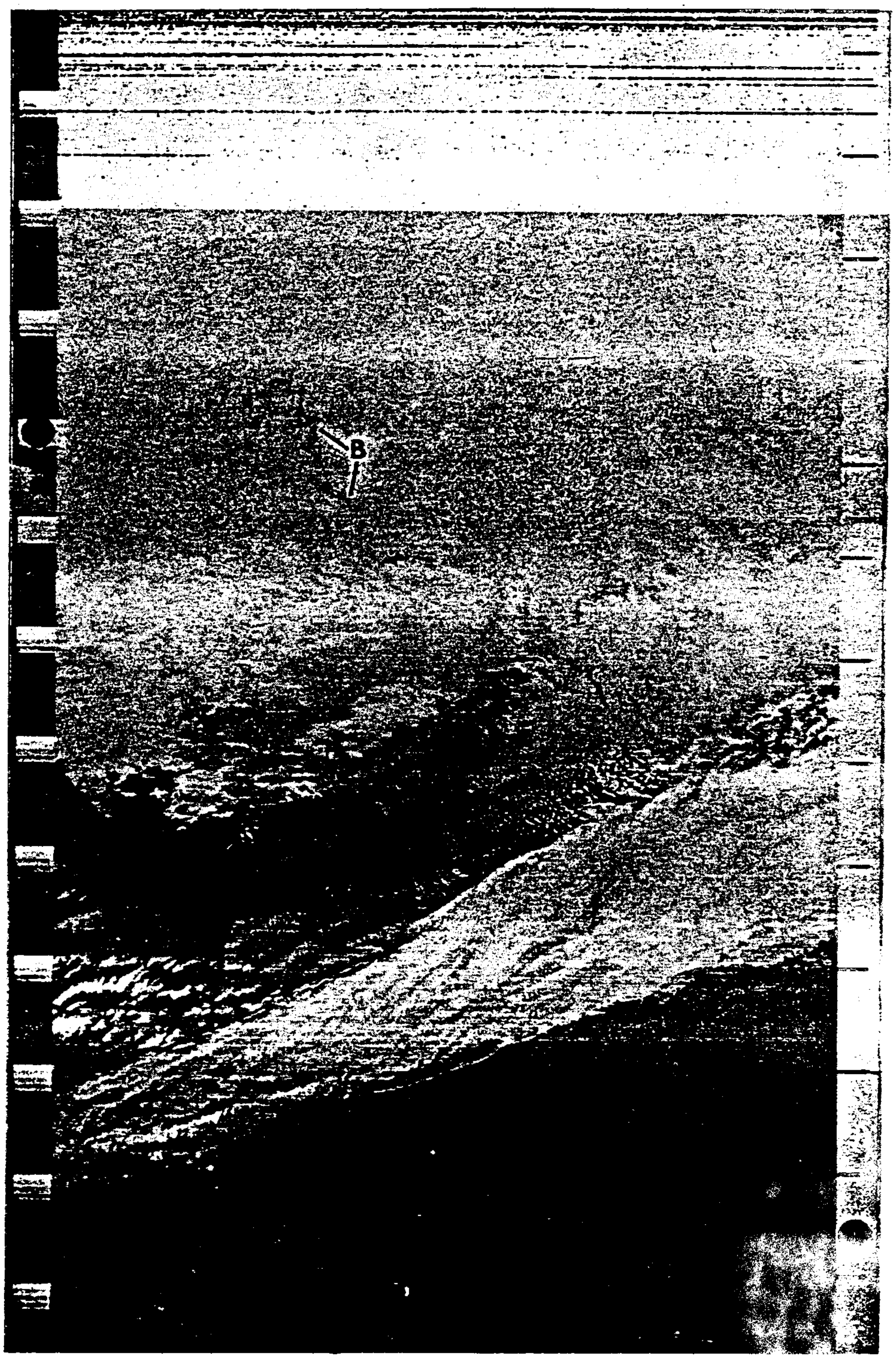


Figure 7-2b TIROS-N enhanced Channel 4 (thermal infrared) APT image showing the same area as Figure 7-2a. This enhanced APT image shows greater detail in both cloud structure and variations in sea surface temperature (A) than does the unenhanced image in Figure 7-1 (a). The Great Lakes (B) and the edge of snow-line (C) can be seen in this image.

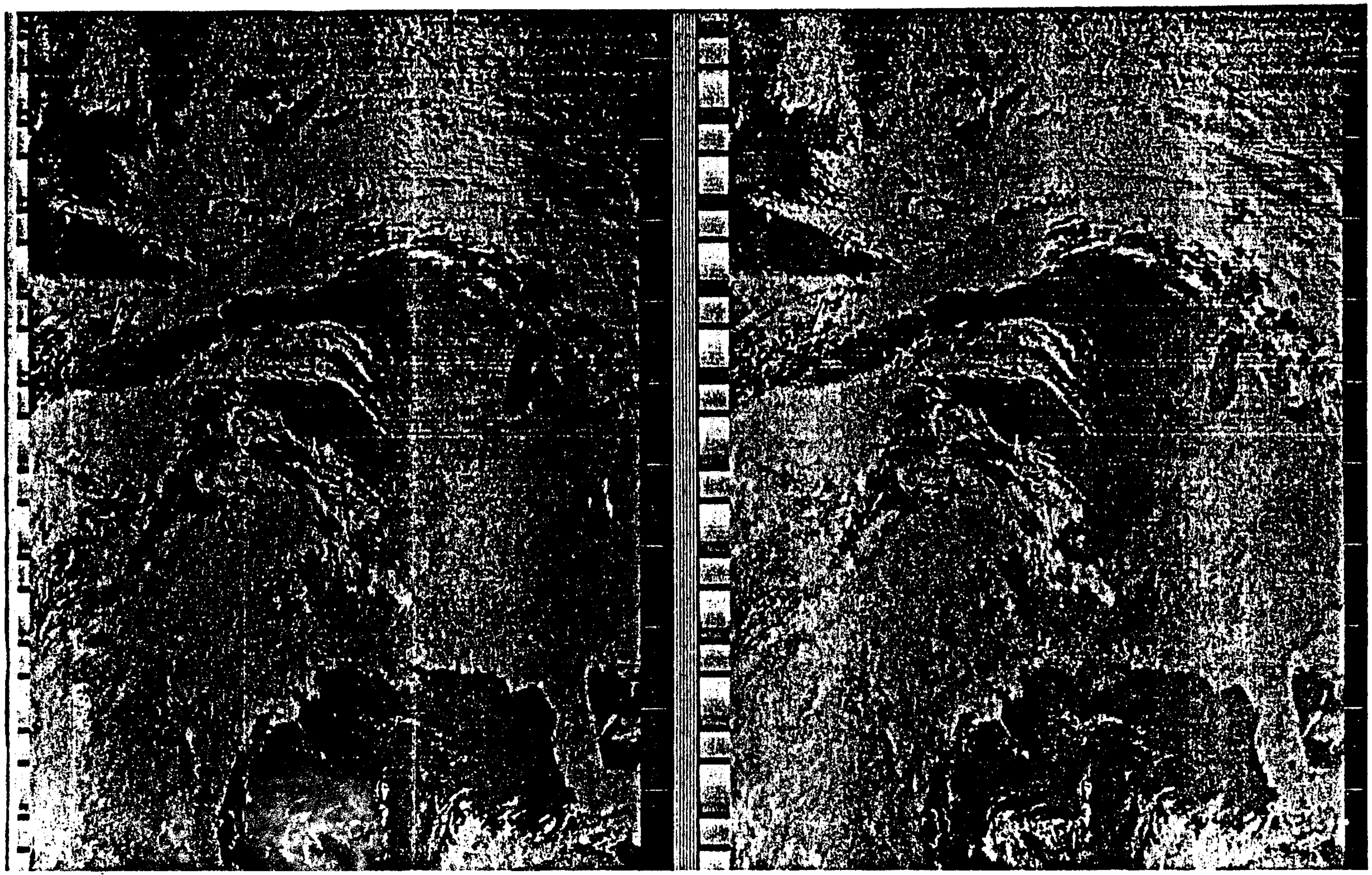


Figure 7-3 TIROS-N APT images viewing the central United States; (a) Channel 2 (0.725 - 1.1 μm) and (b) Channel 1. The Channel 2 image (a) shows greater land/water contrast than the Channel 1 image.

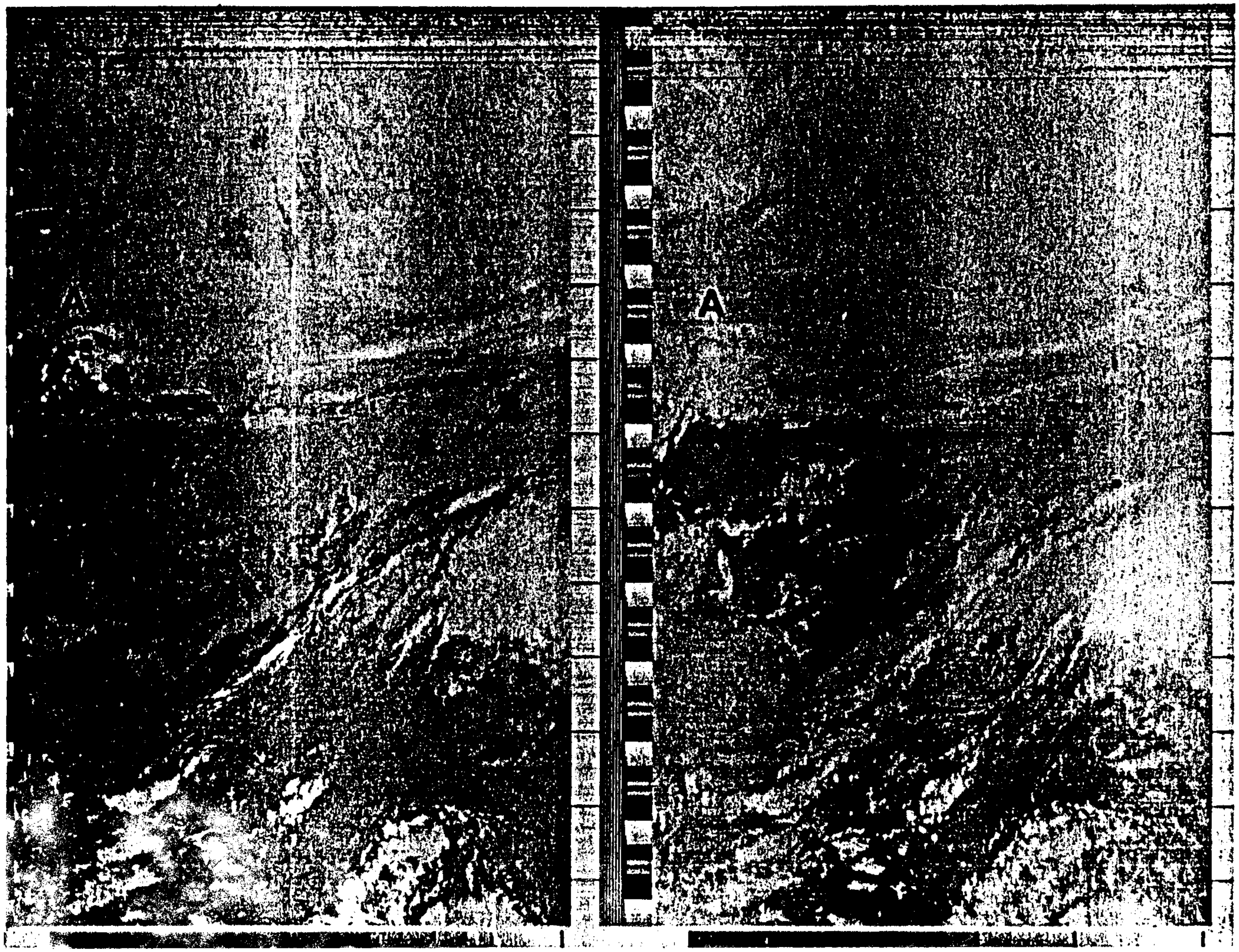


Figure 7-4 TIROS-N enhanced APT images viewing the eastern United States; (a) Channel 3 (3.55 - 3.93 μm) and (b) Channel 4. Note the different responses of clouds at (A) in these two channels.

the left and Channel 4 on the right. Some cloud and land features are difficult to identify in the Channel 3 image because in the daytime the energy detected at that wavelength is a combination of reflected solar energy and emitted energy (temperature). The data shown in these two figures have also been enhanced, similar to the data shown in Figures 7-2(a and b).

With regard to the enhancement of APT data, it is important to remember that only the raw data received directly from the satellite can be enhanced at the APT receiving station using a device such as the Leonessa Engineering K300-140B signal processor. Images transmitted by WEFAX have already been processed at a central processing facility and cannot be enhanced further at the APT station.

7.2 HRPT Data

Images received in the HRPT (or LAC) operational mode are the full-resolution (1.1 km) AVHRR data, whereas images received in the APT (or GAC) mode are the degraded resolution (4 km) data. These operational modes are described in detail in earlier sections.

Examples of daytime HRPT images are shown in Figures 7-5 (a and b). The Channel 1 (visible) image is in Figure 7-5a, and the Channel 4 (IR) image in Figure 7-5b. The area viewed is the eastern United States and part of Canada. On this date (17 February 1979), snow covered most of the eastern part of North America, and an unusually extensive ice cover existed on the Great Lakes; some ice can also be detected in bays along the east coast of the United States. The improved detail of the HRPT as compared to the APT can be seen by comparing Figure 7-5 with Figures 7-1 and 7-2, which view approximately the same area.

Examples of all four AVHRR channels received in the LAC mode are shown in Figures 7-6 (a through d). The LAC images are the same resolution as HRPT, except are recorded on-board the satellite for later transmission on commanded readout to the Command and Data

Figure 7-5(a) TIROS-N HRPT Channel 1 (visible--0.55-0.90 μm) daytime image viewing the eastern United States and Canada. Snow covers most of the land areas viewed, and considerable ice cover exists on the Great Lakes.

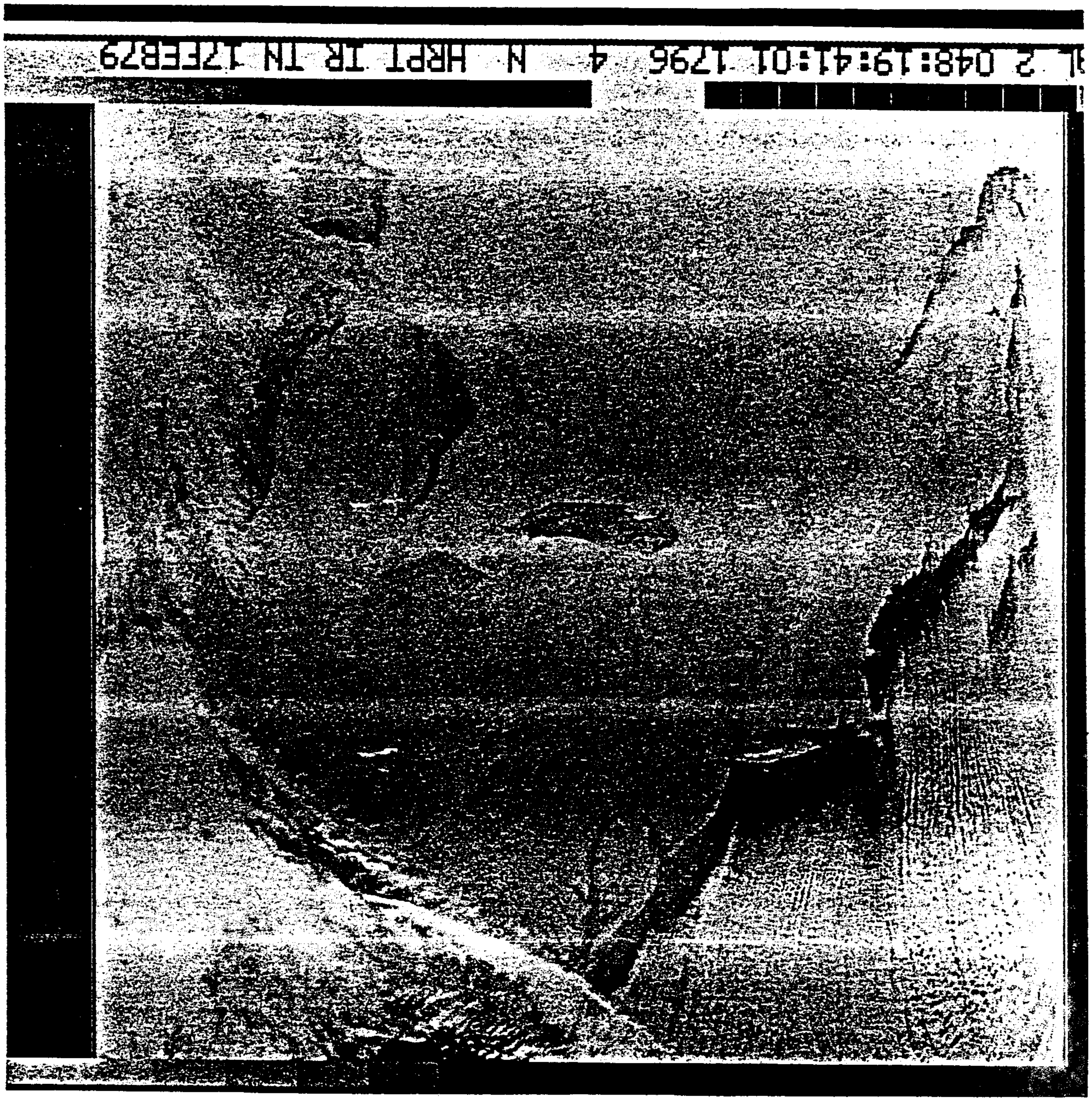


Figure 7-5(b) TIROS-N HRPT Channel 4 (infrared--10.5-11.5 µm)daytime HRPT image taken at the same time and over the same area shown in Figure 7-5(a).

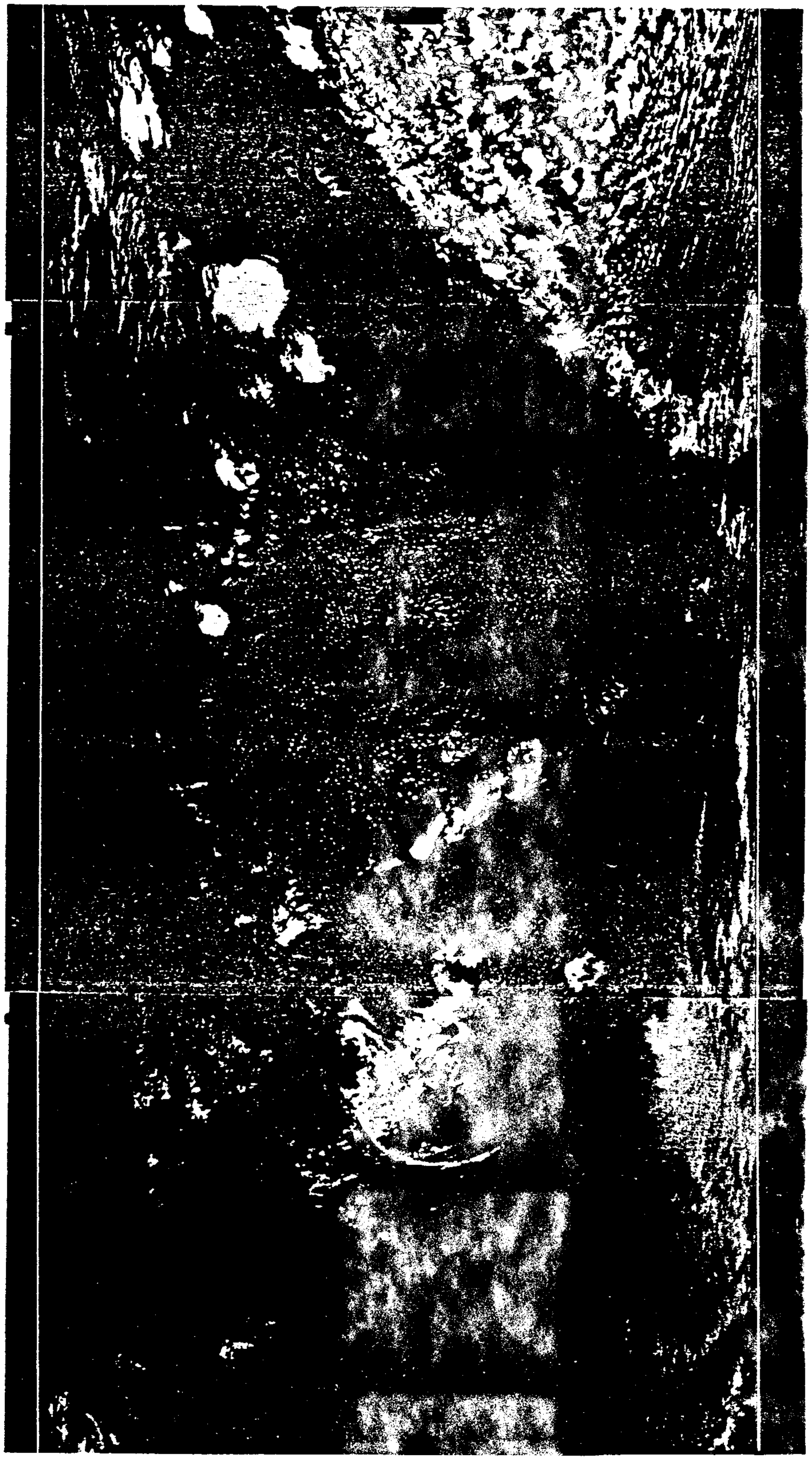


Figure 7-6(a) TIROS-N HRPT Channel 1 (0.55-0.90 μm) daytime image viewing India and Sri Lanka.

Figure 7-6(b) TIROS-N HRPT Channel 2 (0.725-1.1μm) daytime image, same time and area as shown in Figure 7-6(a).

Figure 7-6(c) TIROS-N HRPT Channel 3 (3.55-3.93 μm) daytime image, same time and area as shown in Figure 7-6(a).

Figure 7-6(d) TIROS-N HRPT Channel 4 (10.5-11.5μm) daytime image, same time and area as shown in Figure 7-6(a).

Acquisition Station for relay to the NOAA central processing facility. These images show India and Sri Lanka in daylight; Channels 1 through 4 are shown in Figures 7-6a through 7-6d, respectively.

7.3 Enhancement of Digitized AVHRR Data

At the NOAA/NESS central receiving station at Wallops Station, Virginia; Fairbanks, Alaska; and San Francisco, California; the AVHRR analog signal can be converted to digital form and stored on computer compatible tapes. Using the digital data the sensitivity of the satellite sensor can be fully exploited such that the more subtle temperature differences of the input signal can be made readily apparent to the analyst. This type of sophisticated data processing cannot be accomplished at APT stations, but the user may see examples of the enhanced digitized data in various publications. A reference on digital processing is given in the bibliography.

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APPENDIX A

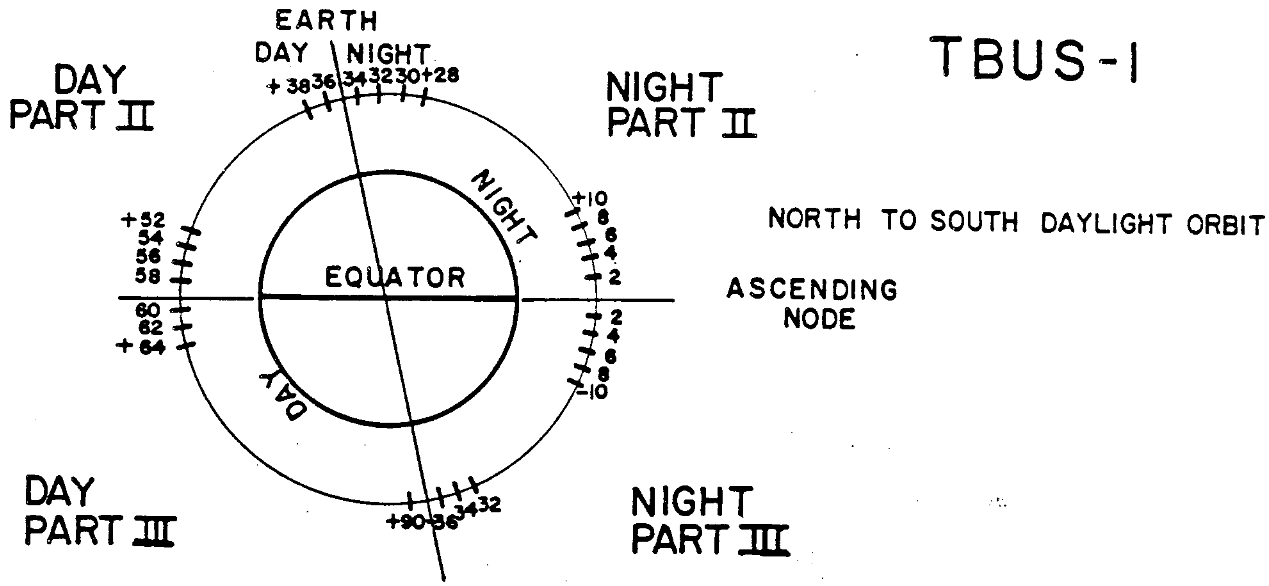
APT PREDICT (TBUS) BULLETIN

APT Predict (TBUS) Bulletin Code

The TBUS is a national practice code form used by the United States to transmit information for predicting the path or locating the position of polar orbiting environmental satellites. It is transmitted daily, at about 1908Z, by KWBC Washington, DC, on the Global Telecommunications Service network.

The TBUS-1 code form is used to convey information about satellites that are descending in daylight (i.e., north to south direction of travel in daytime), while the TBUS-2 code form relates to satellites that are ascending in daylight (south to north).

This Appendix contains:



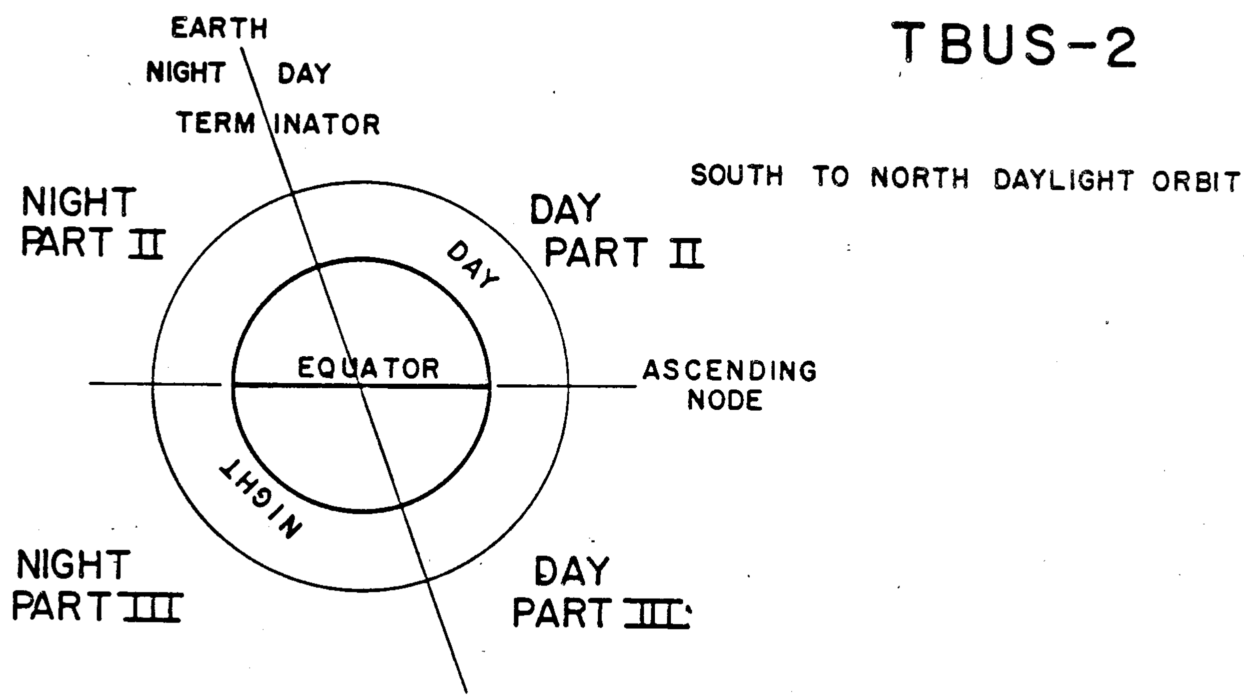


Figure A-1. Schematic representation of difference between TBUS-1 and TBUS-2

Section A.1 THE TBUS-1 CODE FORM

U. S. NATIONAL PRACTICE CODE TBUS-1 FOR SATELLITE EPHEMERIS PREDICT MESSAGE (DAYLIGHT DESCENDING SATELLITES)

TBUS 1 KWBC
APT PREDICT
MMYYSS

PART I

$ON_rN_rN_rN_r$ $OY_rY_rG_rG_r$ $Og_rg_rs_rs_r$ $Q_rL_oL_ol_ol_o$ Tggss $LL_oL_ol_ol_o$

$N_4N_4N_4N_4G_4$ $G_4g_4g_4s_4s_4$ $Q_4L_oL_ol_ol_o$

$N_8N_8N_8N_8G_8$ $G_8g_8g_8s_8s_8$ $Q_8L_oL_ol_ol_o$

$N_{12}N_{12}N_{12}N_{12}G_{12}$ $G_{12}g_{12}g_{12}s_{12}s_{12}$ $Q_{12}L_oL_ol_ol_o$

NIGHT PART II

$02h_{02}h_{02}Q_{02}$ $L_aL_al_aL_oL_ol_o$ $04h_{04}h_{04}Q_{04}$ $L_aL_al_aL_oL_ol_o$

$06h_{06}h_{06}Q_{06}$ $L_aL_al_aL_oL_ol_o$ $ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

...and continuing north, at two-minute intervals, to day/night terminator in N. Hemisphere.

NIGHT PART III

$02h_{02}h_{02}Q_{02}$ $L_aL_al_aL_oL_ol_o$ $04h_{04}h_{04}Q_{04}$ $L_aL_al_aL_oL_ol_o$

$06h_{06}h_{06}Q_{06}$ $L_aL_al_aL_oL_ol_o$ $ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

...and continuing south, at two-minute intervals, to day/night terminator in S. Hemisphere.

DAY PART II

...begins near day/night terminator in N. Hemisphere, two minutes after last position given in NIGHT PART II, continuing south at two-minute intervals and ending close to and north of the equator, repeating the code form:
.....$ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

DAY PART III

...begins two minutes after last position given in DAY PART II. First two code groups give satellite time, height, octant, and latitude/longitude of the first position south of the equator; following groups give the same information at two-minute intervals until spacecraft reaches day/night terminator in S. Hemisphere; repeating code form:

....$g_gh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_oL_o$....

PART IV

AAAAAAAAA BBBBB CCCCCCCCCCCC DDEEFFGGHHIIIII JJJJJJ
KKKKKKKK LLLLLLLL MMMMMMMM NNNNNNNN 00000000 PPPPPPPP
QQQQQQQQ RRRRRRRR SSSSSSSSSS TTTTTTTTTT UUUUUUUUUU VVVVVVVVV
WWWWWWWWW XXXXXXXXX YYYYYYYYY ZZZaaabbb cccc dddddddddd
eeeeeeeee fffffffff ggggggggg SPARESPARE
APT TRANSMISSION FREQUENCY XXX.XX MHz
HRPT TRANSMISSION FREQUENCY XXXX.XX MHz
BEACON (DSB) TRANSMISSION FREQUENCY XXX.XX MHz
APT DAY X/X APT NIGHT X/X
DCS CLOCK TIME DAY XXX XXXXX.X
(ADDITIONAL PLAIN LANGUAGE REMARKS WHEN NEEDED)

- -

CODE SYMBOLS FOR HEADING AND PARTS I-III

MM	-	month
YY	-	day
SS	-	satellite (see Table A-1, below)
NNNN	-	orbit number
GG	-	hour
gg	-	minutes
ss	-	seconds
Q	-	Octant of Globe (see Figure A-2, page A-13)
L_oL_o	-	Longitude (tens and units)
l_o	-	Longitude (tenths)
T^o	-	Group indicator
L	-	Group indicator
hh	-	Height in hundreds and tens of kilometers
L_a	-	Latitude (tens)
l_a	-	Latitude (tenths)

- -

TABLE A-1

Numbers used in TBUS, SATOB, SATEM, SAREP bulletins to identify satellites:

10 - 19	ITOS series satellites
20 - 29	SMS/GOES series satellites
30 - 39	TIROS-N series satellites

Section A.2 THE TBUS-2 CODE FORM

U. S. NATIONAL CODE TBUS-2 FOR SATELLITE EPHEMERIS PREDICT MESSAGE (DAYLIGHT ASCENDING SATELLITES)

TBUS 2 KWBC
APT PREDICT
MMYYSS

PART I

$ON_rN_rN_rN_r$ $OY_rY_rG_rG_r$ $Og_rg_rs_rs_r$ $Q_rL_oL_ol_ol_o$ Tggss $LL_oL_ol_ol_o$

$N_4N_4N_4N_4G_4$ $G_4g_4g_4s_4s_4$ $Q_4L_oL_ol_ol_o$

$N_8N_8N_8N_8G_8$ $G_8g_8g_8s_8s_8$ $Q_8L_oL_ol_ol_o$

$N_{12}N_{12}N_{12}N_{12}G_{12}$ $G_{12}g_{12}g_{12}s_{12}s_{12}$ $Q_{12}L_oL_ol_ol_o$

DAY PART II

$02h_{02}h_{02}Q_{02}$ $L_aL_al_aL_oL_ol_o$ $04h_{04}h_{04}Q_{04}$ $L_aL_al_aL_oL_ol_o$

$06h_{06}h_{06}Q_{06}$ $L_aL_al_aL_oL_ol_o$ $ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

...and continues north, at two-minute intervals, to day/night terminator in N. Hemisphere.

DAY PART III

$02h_{02}h_{02}Q_{02}$ $L_aL_al_aL_oL_ol_o$ $04h_{04}h_{04}Q_{04}$ $L_aL_al_aL_oL_ol_o$

$06h_{06}h_{06}Q_{06}$ $L_aL_al_aL_oL_ol_o$ $ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

...and continuing south, at two-minute intervals, to day/night terminator in S. Hemisphere.

NIGHT PART II

...beginning near day/night terminator in N. Hemisphere, two minutes after last position given in DAY PART II, continuing at two-minute intervals and ending close to and north of the equator; repeating code form:
...$ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

NIGHT PART III

...beginning two minutes after last position given in NIGHT PART II. First two code groups give satellite time, height, octant, and latitude/longitude of the first position south of the equator; following groups give the same information at two-minute intervals until spacecraft reaches day/night terminator in S. Hemisphere; repeating code form:
...$ggh_{gg}h_{gg}Q_{gg}$ $L_aL_al_aL_oL_ol_o$ ....

PART IV

AAAAAAAAA BBBBB CCCCCCCCCCCC DDEEFFGGHHIIIII JJJJJJ

KKKKKKKK LLLLLLLL MMMMMMMM NNNNNNNN 00000000 PPPPPPPP

QQQQQQQQ RRRRRRRR SSSSSSSSSS TTTTTTTTTT UUUUUUUUUU VVVVVVVVV

WWWWWWWWW XXXXXXXXX YYYYYYYYY ZZZaaabbb cccc dddddddddd

eeeeeeeee ffffffff ggggggggg SPARESPARE

APT TRANSMISSION FREQUENCY XXX.XX MHz
HRPT TRANSMISSION FREQUENCY XXXX.XX MHz
BEACON (DSB) TRANSMISSION FREQUENCY XXX.XX MHz
APT DAY X/X APT NIGHT X/X
DCS CLOCK TIME DAY XXX XXXXX.X
(ADDITIONAL PLAIN LANGUAGE REMARKS WHEN NEEDED)

CODE SYMBOLS FOR HEADING AND PARTS I-III

MM	-	month
YY	-	day
SS	-	satellite (see Table A-1, below)
NNNN	-	orbit number
GG	-	hour
gg	-	minutes
ss	-	seconds
Q	-	Octant of Globe (see Figure A-2, page A-13)
L_oL_o	-	Longitude (tens and units)
l_o	-	Longitude (tenths)
T^o	-	Group indicator
L	-	Group indicator
hh	-	Height in hundreds and tens of kilometers
L_a	-	Latitude (tens)
l_a	-	Latitude (tenths)

TABLE A-1

Numbers used in TBUS, SATOB, SATEM, SAREP bulletins to identify satellites:

10 - 19	ITOS series satellites
20 - 29	SMS/GOES series satellites
30 - 39	TIROS-N series satellites

Section A.3 EXPLANATION OF CODE SYMBOLS

TBUS-1 (or TBUS-2)	- APT Bulletin originating in the United States: TBUS-1 is North to South (descending) daylight orbit. TBUS 2 is South to North (ascending) daylight orbit.
KWBC	- Traffic entered at Washington, D. C.
APT PREDICT	- Identifies message content.
MMYYSS	- Message serial number MM - Month YY - Day of Month SS - Number of spacecraft to which predict applies (See Table 1, page A-4)
PART I	- Equator crossing reference information follows
0	- Code group indicator for first three groups
$N_rN_rN_rN_r$	- Number of reference orbit. (Note: Information in Parts II and III also are related to this reference orbit.)
$Y_rY_rG_rG_rg_rg_rs_rs_r$	- Reference orbit equator crossing time (GMT), satellite northbound: Y_rY_r - Day of Month G_rG_r - Hour g_rg_r - Minute s_rs_r - Second

NOTE: In TBUS-1, northbound equator crossing takes place on <u>NIGHT</u> side of orbit. In TBUS-2, northbound equator crossing takes place on <u>DAY</u> side of orbit.

Q_r	- Octant satellite is entering after crossing equator on reference orbit (See Appendix B)
$L_oL_oL_oL_o$	- Reference orbit equator crossing longitude in degrees and hundreths.
T	- Indicator: nodal period follows (always be shown as "T").
gg	- Nodal period, minutes
ss	- Nodal period, seconds. [NOTE: Hundreds group will not be included. Example: 100 minutes 13 seconds will be coded as 0013.
L	- Indicator, nodal longitude increment follows (always shown as "L").

$L_oL_ol_ol_o$ - Degrees and hundreths of degrees longitude between successive equator crossings.

$N_4N_4N_4N_4$ - Orbit number of fourth orbit following reference orbit.

G_4G_4 - Hour of northbound satellite equator crossing four orbits after reference orbit.

g_4g_4 - Minute

s_4s_4 - Second

Q_4 - Octant satellite is entering after crossing equator on fourth orbit after reference orbit.

$L_oL_ol_ol_o$ - Equator crossing longitude of fourth orbit after reference orbit.

Above information is repeated for eighth ($N_8N_8N_8N_8$) and twelfth ($N_{12}N_{12}N_{12}N_{12}$) orbits following reference orbit.

NIGHT PART II (TBUS-1) or DAY PART II (TBUS-2) - Contains satellite altitude and subpoint coordinates at two-minute intervals after time of equator crossing; satellite northbound.

02 - Indicator; satellite altitude and subpoint coordinates at two minutes after time of equator crossing.

$h_{02}h_{02}$ - Altitude, in hundreds and tens of kilometers, at two minutes after equator crossing. (Thousands figure understood; hence 1440 km is encoded as 44.)

Q_{02} - Octant of globe at two minutes after equator crossing.

$L_aL_al_a$ - Latitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.

$L_oL_ol_o$ - Longitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.

(Above information is repeated at two-minute intervals over the NIGHT portion of the orbit north of the equator for TBUS-1, and DAY portion of the orbit north of the equator for TBUS-2.)

NOTE: Should the time after ascending node become greater than 99, the hundreds will be assumed (example, minute 102 will be encoded as 02).

NIGHT PART III (TBUS-1) or DAY PART III (TBUS-2) - Satellite altitude and subpoint coordinates at two-minute intervals south of equator on the descending side of the orbit.

02 - Indicator; satellite altitude and subpoint coordinates at two minutes after time of equator crossing follows.

$h^{02}h^{02}$ - Satellite altitude in hundreds and tens of kilometers at gg minutes after equator crossing.

Q_{02} - Octant of globe at two minutes after equator crossing.

$L_aL_a la$ - Latitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.

$L_oL_o l_o$ - Longitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.

(Above information is repeated at two-minute intervals over the night portion of the orbit south of the equator for TBUS-1, and sunlit portion of the orbit north of the equator for TBUS-2.)

DAY PART II (TBUS-1) NIGHT PART II (TBUS-2) - Satellite altitude and subpoint coordinates at two-minute intervals after time of equator crossing follows.

gg - Information pertinent to gg minutes after equator crossing follows.

$h_{gg}h_{gg}$ - Satellite altitude in hundreds and tens of kilometers at gg minutes after equator crossing.

Q_{gg} - Octant of globe at gg minutes after equator crossing.

$L_aL_a la$ - Latitude of satellite subpoint in degrees and tenths of degrees at gg minutes after equator crossing.

$L_oL_o l_o$ - Longitude of satellite subpoint in degrees and tenths of degrees at gg minutes after equator crossing.

(Above information is repeated at two-minute intervals over the sunlit portion of the orbit north of the equator for TBUS-1, and night portion of the orbit north of the equator for TBUS-2.)

DAY PART III (TBUS-1) or NIGHT PART III (TBUS-2)	- Satellite altitude and subpoint coordinates at two-minute intervals south of the equator on the descending side of the orbit.
02	- Indicator: satellite altitude and subpoint coordinates at two minutes after time of equator crossing.
h	- Satellite altitude in tens of kilometers, at two minutes after equator crossings.
Q_{02}	- Octant of globe at two minutes after equator crossing.
$L_aL_al_a$	- Latitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.
$L_oL_ol_o$	- Longitude of satellite subpoint in degrees and tenths of degrees at two minutes after equator crossing.

(Above information is repeated at two-minute intervals over the sunlit portion of the orbit south of the equator for TBUS-1 and night portion of the orbit south of the equator for TBUS-2.)

NOTE: Should the time after ascending node become greater than 99, the hundreds will be assumed (example, minute 102 will be encoded as 02).

PART IV - (Contains high precision orbital elements, transmission frequencies, and remarks).

Symbol	Explanation
AAAAAAAAA	Spacecraft identification (International designator- see "COSPAR Guide to Rocket and Satellite Information and Data Exchange Information Bulletin #9, July 1962).
BBBBB	Orbit number at epoch.
CCCCCCCCCCCC	Time of ascending node (days from January 1 at 00Z, to nine decimal places.
DD	Epoch year
EE	Epoch month
FF	Epoch day
GG	Epoch hour
HH	Epoch minute
IIIII	Epoch second, to three decimal places
JJJJJJJ	Greenwich Hour Angle at Aries at epoch, to four decimal places.
KKKKKKKK	Anomalistic period (minutes), to four decimal places.
LLLLLLLL	Nodal period (minutes), to four decimal places.
MMMMMMMM	Eccentricity, to eight decimal places.
NNNNNNNN	Argument of perigee (degrees), to five decimal places.
OOOOOOOO	Right Ascension of the ascending node (degrees) to five decimal places.
PPPPPPPP	Inclination (degrees), to five decimal places.
QQQQQQQQ	Mean anomaly (degrees), to five decimal places.
RRRRRRRR	Semi-major axis (km), to three decimal places.
SSSSSSSSSS	Sign and epoch X position component (km), to four decimal places.
TTTTTTTTTT	Sign and epoch Y position component (km), to four decimal places.

Symbol (Cont.)	Explanation (Cont)
UUUUUUUUUU	*Sign and epoch Z position component (km), to four decimal places.
VVVVVVVVV	*Sign and epoch X velocity (Xdot) component (km/sec), to six decimal places.
WWWWWWWWW	*Sign and epoch Y velocity (Ydot) component (km/sec), to six decimal places.
XXXXXXXXX	*Sign and epoch Z velocity (Zdot) component (km/sec), to six decimal places.
YYYYYYYYY	Ballistics coefficient CD-A/M (m^2/kg), to eight decimal places.
ZZZ	Daily solar flux value (10.7 cm) (10^{-7} watt/m^2).
aaa	90-day running mean of solar flux (10^{-7}watts/m^2).
bbb	Planetary magnetic index ($2x10^{-5}$ gauss).
cccc	Drag modulation coefficient, to four decimal places.
dddddddddd	Radiation pressure coefficient (m^2/kg), to ten decimal places.
eeeeeeeee	Sign and perigee motion (deg/day), to five decimal places.
ffffffff	Sign and motion of Right Ascension of the ascending node (deg/day), to five decimal places.
gggggggg	Sign and rate of change of mean anomaly at epoch (deg/day), to two decimal places.
SPARESPARE	spares

---

*-- All signed values in PART IV are preceeded by a "P" or "N" to denote a plus (+) or minus (-)value.

APT TRANSMISSION FREQUENCY XXX.XX MHz
HRPT TRANSMISSION FREQUENCY XXXX.XX MHz
BEACON (DSB) TRANSMISSION FREQUENCY XXX.XX MHz
APT DAY X/X APT NIGHT X/X where X will identify channels being used.
DCS CLOCK TIME DAY XXX XXXXX.X
Followed by PLAIN LANGUAGE messages when necessary.

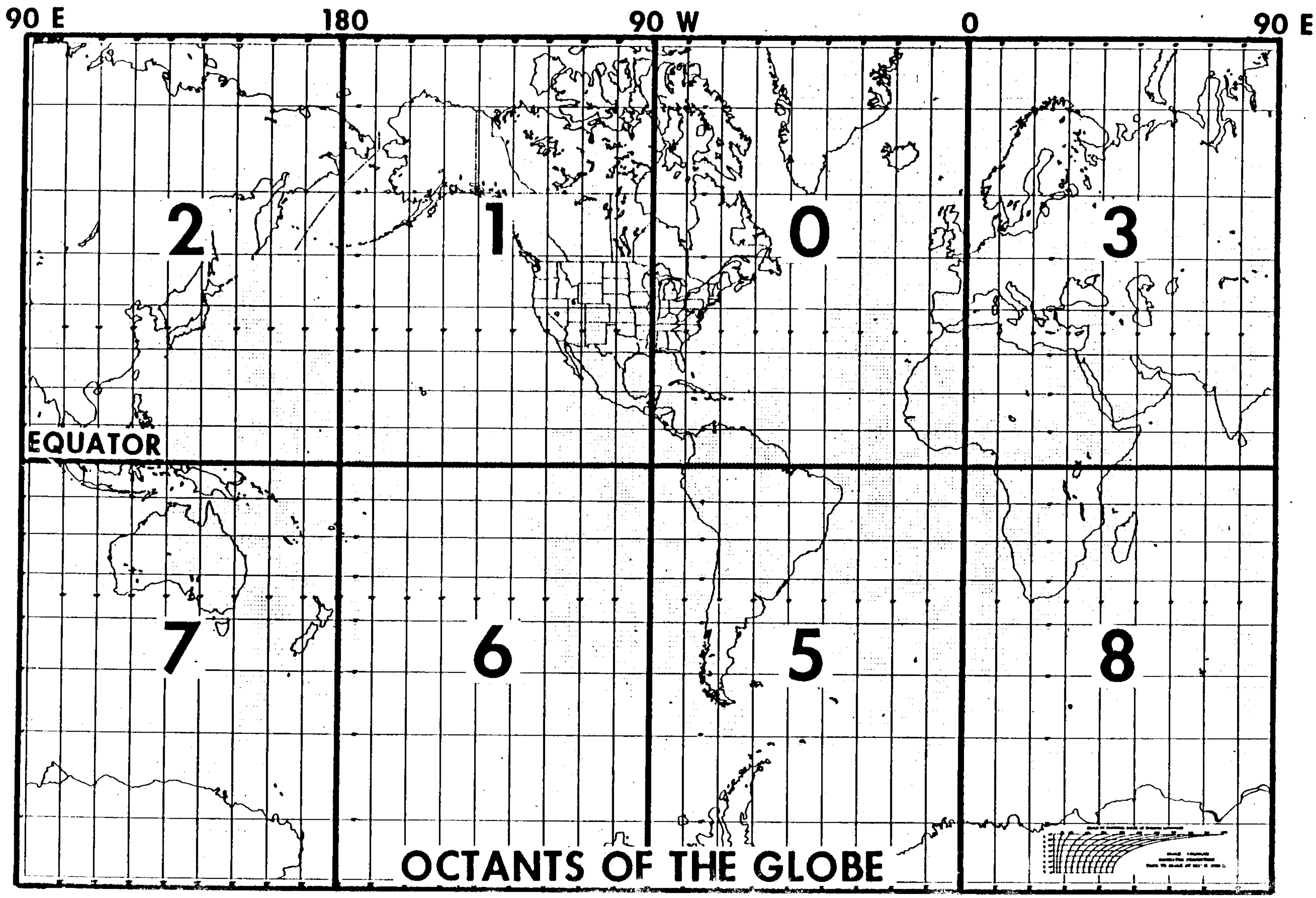


Figure A-2 Global Octant Map

Section A.4 SAMPLE APT PREDICT (TBUS) BULLETIN

The following encoded APT Predict (TBUS) Bulletin example is referred to throughout the remaining appendices. The major features of the message are decoded on the following pages.

```
TBUS2 KWBC 211900
APT PREDICT
062430 TIROS N


PART I
08749 02416 01653 01146 T0202 L2550
87532 30503 11349
87570 55311 24446
87611 24121 34243
DAY   PART II
02840 070132 04840 140149 06840 21066
08840 28084 10840 350204 12840 419227
14840 488255 16840 55689 18840 623336
20840 688407 22840 749529 24840 796776
26841 808200 28841 774538 30841 717705
32851 654794 34842 588749 36842 520710
38842 452679
DAY   PART III
02845 070100 04855 140083 06855 210066
08855 280048 10855 350028 12845 419005
14868 488022
NIGHT PART II
40852 383655 42852 313633 44842 244614
46842 174596 48842 104580 50852 034563
NIGHT PART III
52857 035547 54857 105531 56857 175514
58857 244497 60857 314478 62857 383456
64857 452431 66857 520401 68857 588362
70857 654306 72857 717217 74857 773050
76858 808714 78858 797290 80858 749043
82855 689079 84845 624150 86845 557197
88845 489232 90845 420259
PART  IV
1979 057A 09345 105066560150 810414203210007 1509616
01011681 01012254 00124732 17142454 13773458 09867899
18869440 07189253 M053313427 P048448725 M000019396
P00759127 P00825300 P07350534 003263350 245206018 9449
0000499998 M00290091 P00098722 P00512415 SPARESPARE

APT TRANSMISSION FREQUENCY 137.62 MHZ
HRPT TRANSMISSION FREQUENCY 1707 MHZ
BEACON (DSB) FREQUENCY 137.77 MHZ
APT DAY/NIGHT 1/4 APT IR CHANNEL 4 (10.5 to 11.5 MICROMETERS)
AND VIS CHANNEL 1 (0.55 to 0.90 MICROMETERS)
WILL BE TRANSMITTED CONTINUOUSLY.
DCS CLOCK TIME DAY 088 41126.4
```

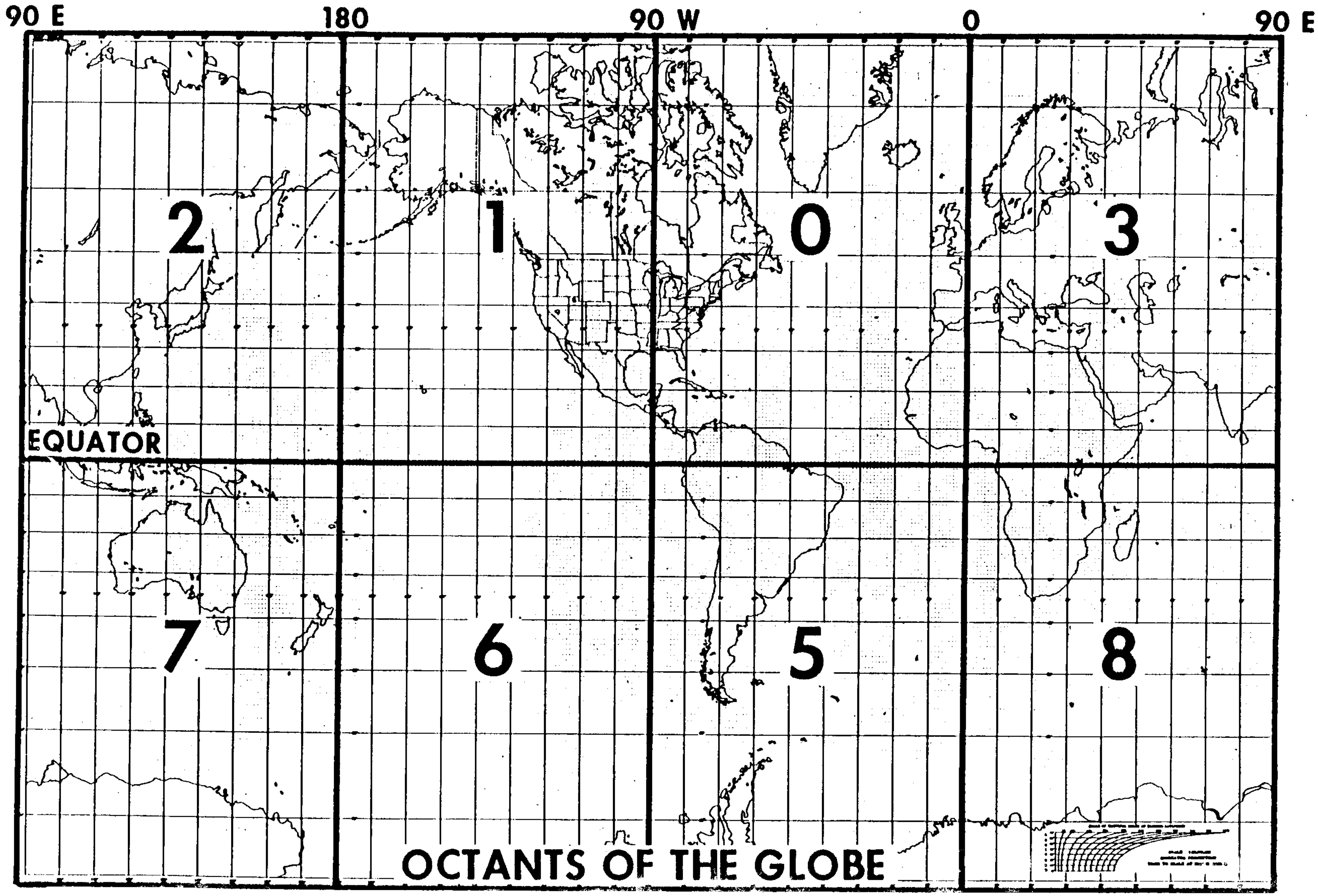


Figure A-2 Global Octant Map

Section A.5 Decoding Excercise

<u>TBUS2</u> <u>KWBC</u> <u>211900</u>

TBUS2	- Bulletin heading--identifies bulletin for satellite southbound in daylight
KWBC	- Bulletin source--Washington, D. C. Communications Center
211900	- 21 -Day of the month--21st - 1900 -Bulletin broadcast time--1900z
<u>APT PREDICT</u>	- Bulletin identifier
<u>062430</u>	- Message serial number 06 --month -- June 24 --Day for which bulletin applies -- 24th 30 --Satellite identifier (see code table A-1, page A-4.)
<u>TIROS N</u>	- Plain language satellite identifier
<u>PART I</u>	- Identifies reference orbit information and the orbital height, equator crossing, longitude and equator crossing time for the fourth, eighth, and twelfth orbits after the reference orbit.

<u>08749 02416 01653 01146 T0202 L2550</u>

08749	0 - Group indicator 8749 - Reference orbit number
02416	0 - Group indicator 24 - Day of month of equator crossing 16 - Hour
01653	0 - Group indicator 16 - Minutes 53 - Seconds (time of equator crossing 16:16:53z)
01146	0 - Octant 0 (0° to 90°), N. Hemisphere 1146 - 011.46°W (equator crossing longitude for orbit 8749 in octant 0)
T0202	T - Group indicator 0202 - Orbital period 102 minutes 02 seconds
L2550	L - Group indicator 2550 - Nodal longitudinal increment 25.50°

87532 30503 11349

87532 30503	8753	- Orbit number 8753 (4th orbit after reference orbit)
	2 30503	- Time (23:05:03z) of ascending node for orbit 8753
11349	1	- Octant 1 (90°W to 180°)
	1349	- 113.49°W (equator crossing for orbit 8753 in octant 1)
87570 55311 24446 87611 24121 34243		- Decoded in same manner as previous underlined line of data
DAY PART II		- Contains satellite altitude and subpoint coordinates at two-minute intervals after time of Northbound (ascending) equator crossing.

02840 070132 04840 140149 ....

02840	02	- Minute 02 after Northbound equator crossing
	84	- Spacecraft height 840km
	0	- Octant 0 (0° to 90°W), N. Hemisphere
070132	070	- Latitude 07.0°N
	132	- Longitude 013.2°W
04840	04	- Minute 04 after Northbound equator crossing
	84	- Spacecraft height 840 km
	0	- Octant 0 (0° to 90°W), N. Hemisphere
140149	140	- Latitude 014.0°N
	149	- Longitude 14.9°W

Remainder of DAY PART II decoded in same manner. Data for DAY PART II are continuous at 2-minute intervals from equator North to Northern terminator.

DAY PART III	- Contains satellite altitude and subpoint coordinates at two-minute intervals South of the equator. satellite Northbound in the Southern Hemisphere (Points are plotted Southward from the equator).

<u>02845 070100 04855 140083</u> ....

02845	02 - Minute 02 before Northbound equator crossing
	84 - Spacecraft height 840 km
	5 - Octant 5 (0 to 90°W, S. Hemisphere)
070100	070 - Latitude 07.0°S
	100 - Longitude 010.0°W
04855	04 - Minute 04 after equator crossing
	85 - Spacecraft height 850 km
	5 - Octant 5 (0 to 90°W, S. Hemisphere)
140083	140 - Latitude 14.0°S
	083 - Longitude 08.3°W

Remainder of DAY PART II decoded in same manner

<u>NIGHT PART II</u> - Satellite altitude and subpoint coordinates at two-minute intervals beginning at the day/night terminator in the N. Hemisphere and continuing southward toward the equator.

<u>40862 383655 42862 313633</u> ....

40852	- 40 - Minute 40 after Northbound equator crossing
	- 85 - Spacecraft height 860 km
	- 2 - Octant 2 (90°E to 180°, N. Hemisphere)
383655	- 383 - Latitude 38.3°N
	- 655 - Longitude 165.5°E
42852	- 42 - Minute 42 after equator crossing
	- 85 - Spacecraft height 860 km
	- 2 - Octant 2 (90°E°e to 180°, N. Hemisphere)
	- 313 - Latitude 31.3°N
	- 633 - Longitude 163.3°E

Remainder of NIGHT PART II decoded in same manner. Data continuous at 2-minute intervals.

<u>NIGHT PART III</u> - Satellite altitude and subpoint coordinates at two-minute intervals south of the equator on the descending side of the orbit.

52867 035547 54867 105531...... ....

52857	- 52 - Minute 52 after Northbound equator crossing - 85 - Spacecraft height 860 km - 7 - Octant 7 (90°E to 180°, S. Hemisphere)
035557	- 035 - Latitude 03.5°S - 547 - Longitude 154.7°E
54857	- 54 - Minute 54 before equator crossing - 85 - Spacecraft height 860 km - 7 - Octant 7 (90°E to 180°, S. Hemisphere)
105531	- 105 - Latitude 10.5°S - 531 - Longitude 153.1°E

Remainder decoded in same manner. Data continuous at 2-minute intervals from first point South of equator to Southern terminator.

<u>PART IV</u> - Indicator -- orbital elements, transmission frequencies, and remarks follow.

AAAAAAAAA	1979-057A	1979-057A International designator
BBBBB	09345	revolution 9345
CCCCCCCCCCC	105066560150	105.066560150 days
DDEEFFGGHHIIIII	810414203210007	81--1981 year 04--04 months 14--14 days 20--20 hours 32--32 minutes 10007--10.007 seconds
JJJJJJJ	1509616	150.9616 degrees
KKKKKKKK	01011681	101.1681 minutes
LLLLLLLL	01012254	101.2254 minutes
MMMMMMMM	00124732	0.00124732 no units
NNNNNNNN	17142454	171.42454 degrees
00000000	13773458	137.73458 degrees
PPPPPPPP	09867899	98.67899 degrees
QQQQQQQQ	18869440	188.69440 degrees
RRRRRRRR	07189253	7189.253 km

SSSSSSSSSS	M053313427	-5331.3427 km
TTTTTTTTTT	P048448725	+4844.8725 km
UUUUUUUUUU	M000019396	-1.9396 km
VVVVVVVVV	P00759127	+0.759127 km/sec
WWWWWWWWW	P00825300	+0.825300 km/sec
XXXXXXXXX	P07350534	+7.350534 km/sec
YYYYYYYYY	003263350	0.03263350 m2/kg
ZZZaaabbb	245206018	245--245 x 10^{-7} watt/m^2 206--206 x 10^{-7} watt/m^2 018--36 x 10^{-5} gauss
cccc	9449	0.9449 no units
dddddddddd	0000499998	0.000499998 m^2/kg
eeeeeeeee	M00290091	-2.90091 degrees/day
fffffffff	P00098722	+0.98722 degrees/day
ggggggggg	P00512415	+5124.15 degrees/day
SPARESPARE	SPARESPARE	No information at this time

APT TRANSMISSION FREQUENCY 137.62 MHZ
HRPT TRANSMISSION FREQUENCY 1707 MHZ
BEACON (DSB) FREQUENCY 137.77 MHZ
APT DAY/NIGHT 1/4 APT IR CHANNEL 4 (10.5 TO 11.5 MICROMETERS)
AND VIS CHANNEL 1 (0.55 TO 0.90 MICROMETERS)
WILL BE TRANSMITTED CONTINUOUSLY.
DCS CLOCK TIME DAY 088 41126.4 - DATA COLLECTION SYSTEM CLOCK TIME RESET FOR JULIAN DAY 088, 41126.4 SECONDS

- -

NOTE: The classical elements (Keplerian) from MMMMMMMM to RRRRRRRR are (Brower) mean elements; the position and velocity components SSSSSSSSSS to XXXXXXXXX are actual. The Greenwich Hour Angle initially will be put out as mean siderial time; it is expected to eventually become apparent siderial time.

The paramenter "time of the ascending node" (i.e., CCCCCCCCCCCC) is presently being reevaluated. It may be to changed to "epoch time minus time of the ascending node crossing prior to epoch (in minutes)". Thus, the user could compute the time of the northbound equator crossing prior to epoch instead of the time for an arbitrary northbound equator crossing. Naturally any changes would be announced.

APPENDIX B

Plotting Board Preparation

B.1 General Procedures

a. Obtain an APT plotting board and appropriate tracking diagram (see details in B.3, below).

b. Attach a clear plastic overlay covering the area encompassed by the equatorial circle.

c. Obtain a TBUS bulletin from the Global Telecommunications Service teletype network or request a copy of satellite subpoints from the Coordinator, Direct Readout Services.

d. Plot satellite subpoint positions at two-minute intervals on the plastic overlay.

e. Determine the equator crossing zones for satellites passing within receiving range of the station.

B.2 Orbital Track

The first APT "plotting boards" were Northern and Southern Hemisphere polar stereographic projections reproduced on one-eighth inch hard plastic. They were designed and produced in the early 1960's by a commercial company under contract to the Government, for use by U. S. Weather Bureau and other professional meteorological stations. Copies of these original boards are available today from a commercial company for approximately $150 (US). Plotting boards provided by the National Earth Satellite Service to APT station operators are reproductions of the original "board" printed on high quality paper.

The first step in preparing the plotting board for satellite tracking is to mount the board on a firm surface such as a stiff piece of cardboard or heavy-weight paper. Next, overlay the plotting board with a clear piece of plastic or film. The plastic should be at least 18 x 18 inches (46 x 46 cm) square -- large enough to cover the entire area within the equatoral circle. Attach the overlay to the plotting board with a pin or screw through the center, or Pole, so that it can be easily rotated.

Next, plot orbital subpoints at two-minute increments. An information sheet containing the orbital subpoint positions for a single orbit of any one of the TIROS-N series satellites can be obtained upon request from the Coordinator, Direct Readout Services. Additionally, the same information can be obtained by decoding a TBUS bulletin. Two-minute subpoints for a satellite travelling south in daylight are contained in TBUS-1 NIGHT PART II and DAY PART II. For a satellite northbound in daylight, TBUS-2 DAY PART II and NIGHT PART II can be used.

Plot these points starting at the equator; continue toward the Pole. The track of the orbit will pass near, but not over, the Polar region. Continue plotting the track until the equatorial line on the other side of the map projection is reached. Draw a smooth curve through these points. It would help to put one or two arrowheads on this curve to indicate direction of tra

Number each point to indicate two-minute intervals. On a Northern Hemisphere map projection, the equator crossing should be marked as minute "0", the first point north of the equator would be minute 02, followed by 04, 06.....etc. On a Southhern Hemisphere map projection, the equatorial crossing should be marked minute 51, followed by 53 (first point below equator), 55, 57, etc.

The orbital plot which has just been completed is representative of a typical orbit for a given satellite with an orbital period of approximately 102 minutes. The time markers are only indicators showing the position of the satellite "X" minutes after an equator crossing. In practice, these numbers would have specific time values for a given orbit. For example, for an equator crossing at 16:10:55Z, minute 02 would have the value 16:12:55Z. This numbering will become more obvious later.

Before moving the plotted track, mark off increments 25.50°, 51.0°, and 76.5° east and west of the equator crossing position. Place small tic-marks on the line of the equator at these points. These represent equator crossing positions -1, -2, and -3 (east) and +1, +2, and +3 (west) before and after the reference orbit crossing. These are nodal longitude increments (each 25.50° apart) determined from PART 1, code group L, of the TBUS bulletin.

B.2 Tracking Diagram

A tracking diagram is used in conjunction with the plotting board to permit the operator to graphically compute azimuth and distance of a spacecraft from the antenna site to any point along the satellite track. The concentric curves (near-ellipses) are isopleths of great circle arc distance drawn at two-degree (222 km or 120 nm) intervals. Section 5.4.1 of the text discusses the theory of determining azimuth and elevation using this diagram.

*Tracking diagrams have been computed for each five degrees of latitude. In the exercise in this report, the antenna site is at 38.0°N, 75.2°W (Wallops Island, Virginia readout site). Therefore, the tracking diagram for 40° latitude is used. The diagram is permanently attached to the plotting board, under the plastic overlay, with the center of the diagram on the latitude and longitude of the receiving antenna and the 0°-180° line parallel to the longitude line of the station.

---

*These diagrams can be ordered, without charge, from:

Coordinator, Direct Readout Services, S/DS21
National Earth Satellite Service
National Oceanic and Atmospheric Administration
Washington, D. C. 20233

Important Notice: These tracking diagrams originally were prepared for use with the early TIROS, ESSA, and ITOS series of satellites having orbital altitudes between 1400-1600 km. The outer circle represents an arc length of 36°, the zero-elevation angle for a satellite at a height of 1500 km (see Table 5-1). The average height, or altitude, of TIROS-N series satellites is 850 km (425nm). Therefore, a circle (ellipse) representing an arc length of 28.1° (from Table 5.1) indicates the zero-elevation angle for TIROS-N series satellites. This is the "acquisition circle"; it has been drawn heavier than other circles on the diagram.

B.3 Determining orbits within reception zones.

Figure B-1 shows the APT Plotting Board with the reference orbit plotted from the APT Predict (TBUS) Bulletin in Appendix A. The equator crossing longitude of the Reference Orbit (#8749) is 11.46°, according to the TBUS bulletin. The tracking diagram has been properly positioned for the station location as described above.

Using a Northern Hemisphere Plotting Board, turn the overlay so that the orbit track is east of the station and tangent to the zero-elevation circle (28.1° arc length), as shown in Figure B-2a. The direction of travel should be northbound, with the minute markers increasing in value. Note the equator crossing longitude. For the station position used in this exercise, the equator crossing longitude is 143°E. Now turn the track clockwise so it is tangent to the zero-elevation circle west of the station, as shown in Figure B-2b, and note the longitude. For the sample exercise station, this would be 67°E.

For this station, any TIROS-N series satellite southbound in daylight will pass within receiving range of the station if the equator crossing occurs between 67°E and 143°E. This range, or zone, is therefore marked by a heavy line on the equator. (It is also true that a satellite crossing the equator in this zone in daylight will pass with range of the station at night).

To determine the equatorial crossing zone for nighttime passes, the same technique is used. The track is positioned so it is tangent to the zero-elevation circle west of the station. The equator crossing longitude is 24°W. The track is then rotated so it is tangent east of the station; the longitude noted is 102°W (figures B-2c and 2d, respectively). The zone is marked as a heavy line on the equator. Any satellite crossing the equator within this zone northbound, day or night, will pass in range of the station.

The same technique is used in the Southern Hemisphere, using a Southern Hemisphere Plotting Board.

B.4 Maximum spacecraft acquisition period during one full orbit

The maximum acquisition period occurs when the spacecraft passes direct' over the station. To determine when this would occur, position the track so that it passes directly through the center of the tracking diagram (and therefore over the station). For a satellite passing over the station southbound, the equator crossing will occur at about 108°E and the satellite will be within range from minute 32 to minute 48 after the equator crossing time. If the satellite is passing over the station northbound the equator crossing longitude for a full pass over the station would be 65°W and the spacecraft would be within range from 03 minutes to 19 minutes from the time of equator crossing.

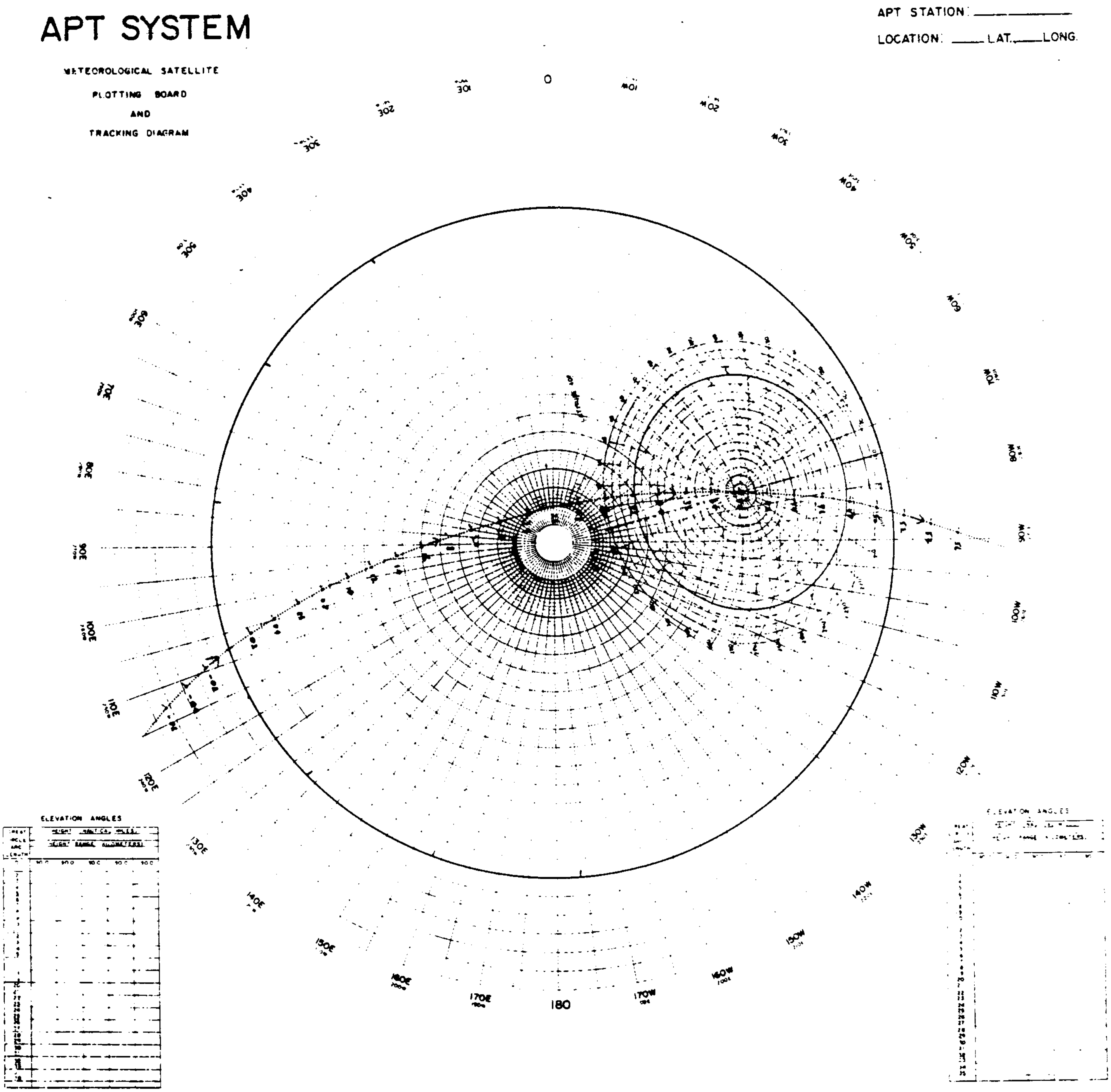


Figure B-1. Plotting board with the plotted subpoint track set at 11.46°W, the equator crossing longitude of the Reference Orbit (#8749). Satellite northbound.

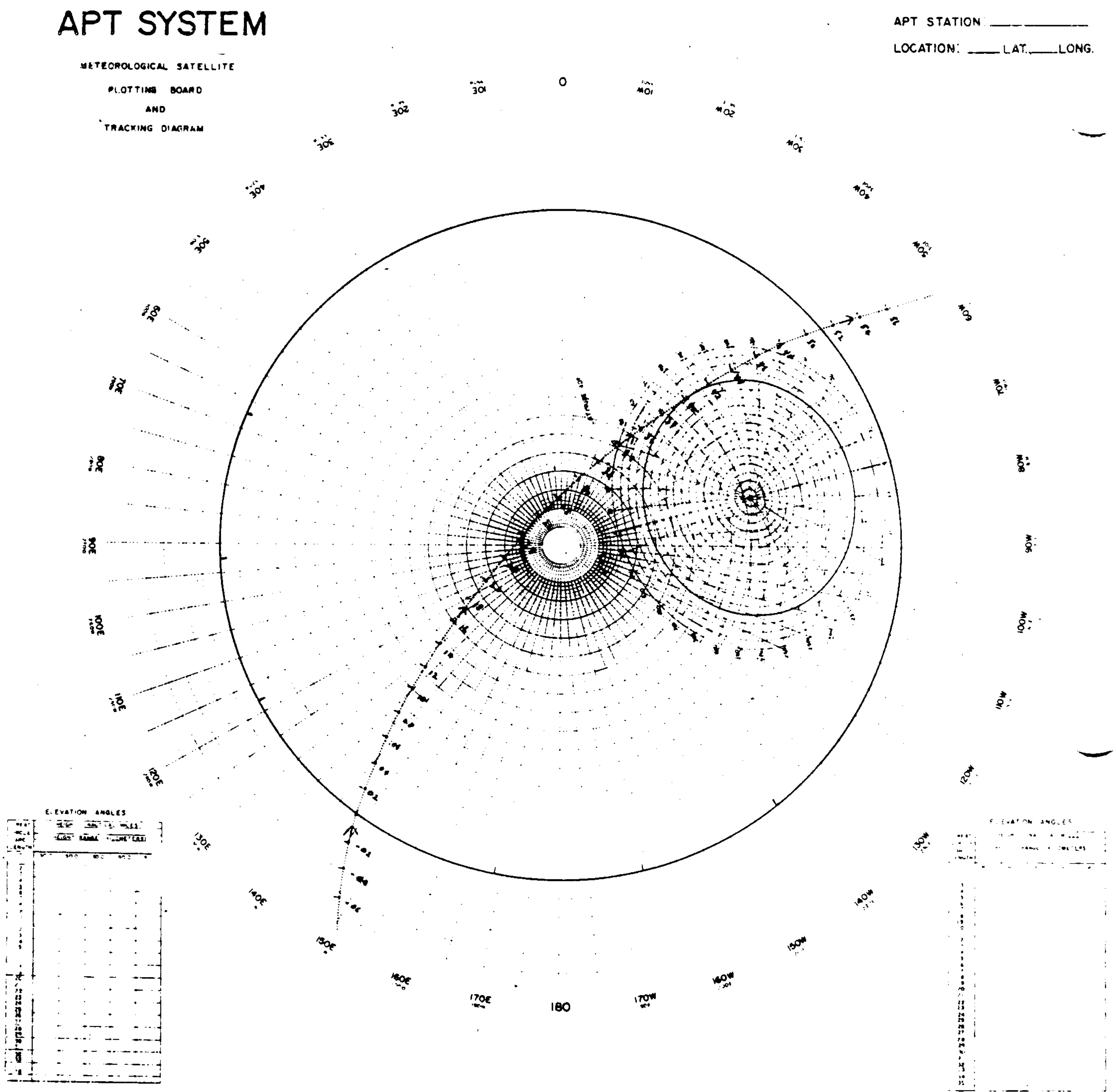


Figure B-2a. Plotting board with the plotted subpoint track set tangent to the zero-degree elevation circle, east of the station. Satellite northbound. The equator crossing longitude is observed to be at 143°E.

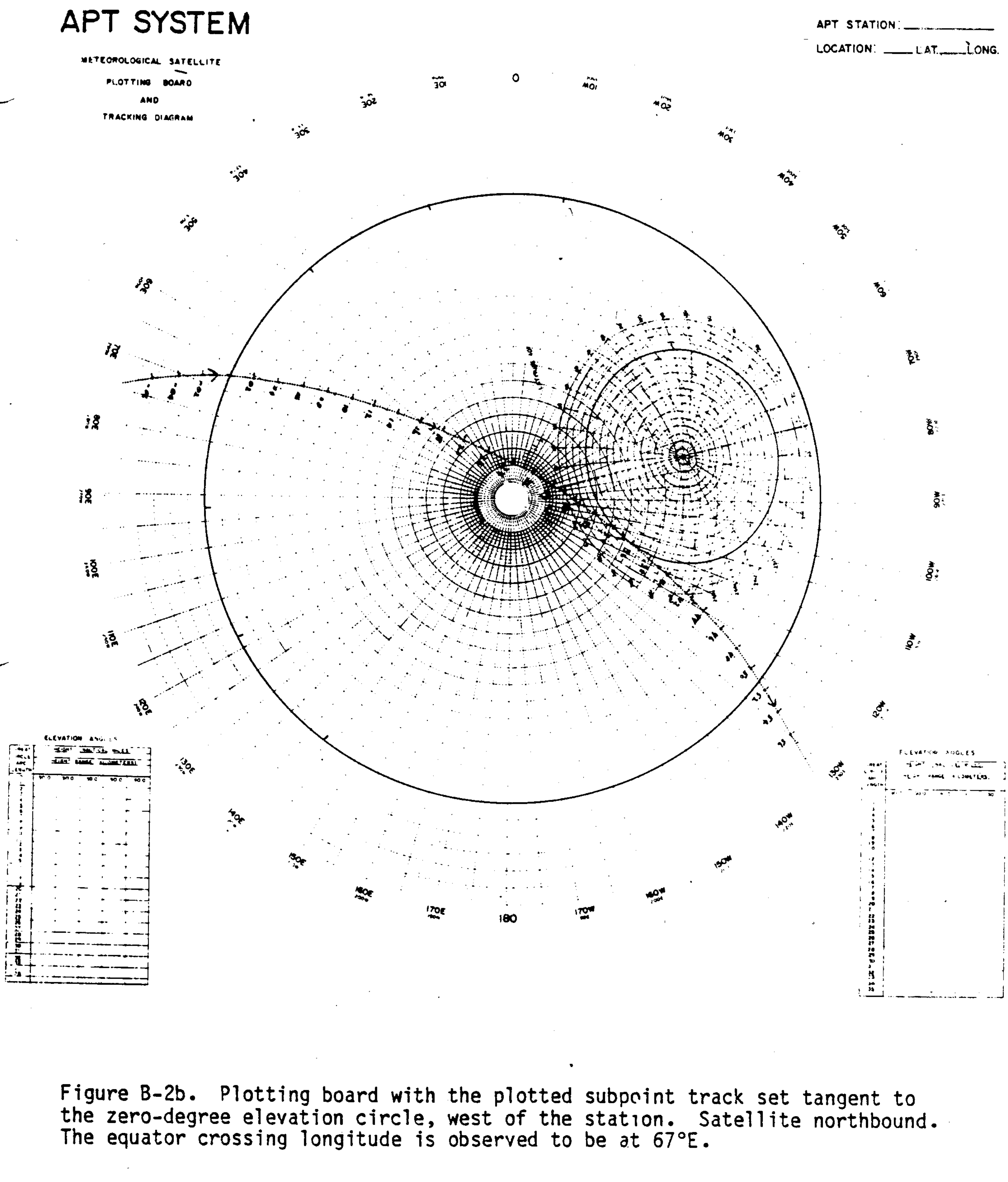


Figure B-2b. Plotting board with the plotted subpoint track set tangent to the zero-degree elevation circle, west of the station. Satellite northbound. The equator crossing longitude is observed to be at 67°E.

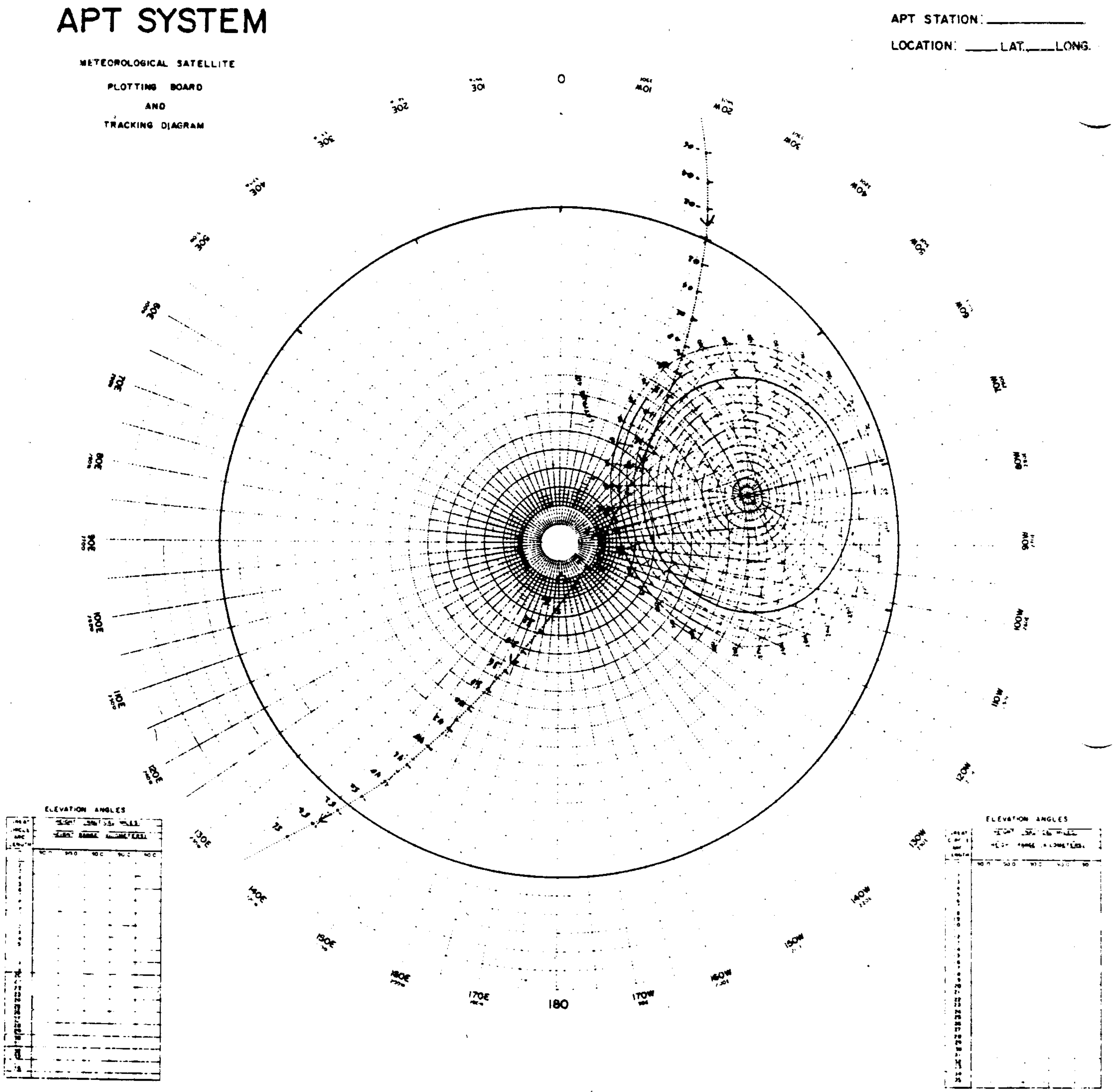


Figure B-2c. Plotting board with the plotted subpoint track set tangent to the zero-degree elevation circle, east of the station. Satellite southbound. The equator crossing longitude is observed to be at 24°W.

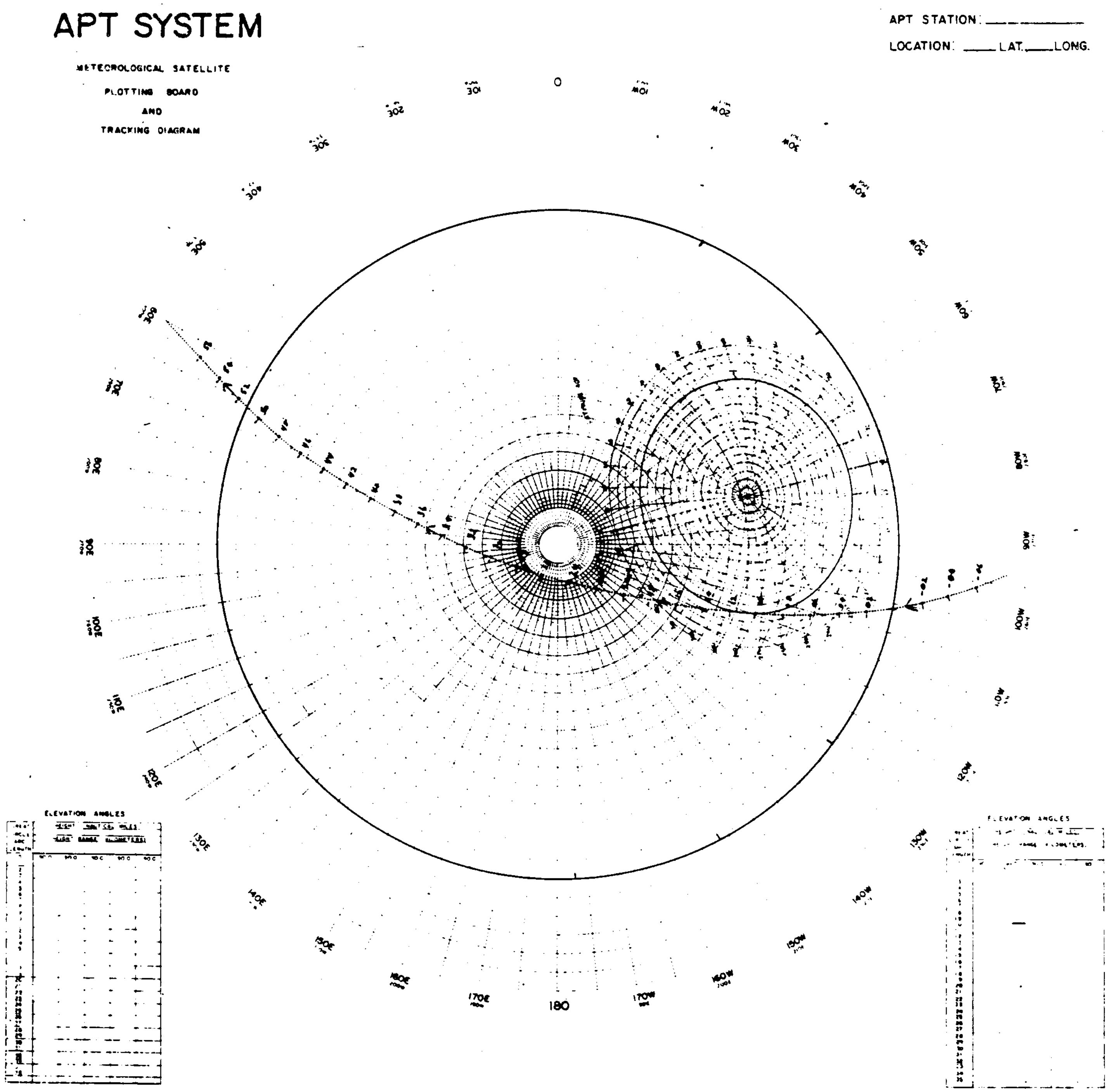


Figure B-2d. Plotting board with the plotted subpoint track set tangent to the zero-degree elevation circle, east of the station. Satellite southbound. The equator crossing longitude is observed to be at 102°W.

APPENDIX C

TRACKING EXERCISE

Given an orbit number, equator crossing time and longitude, the period of revolution, and the longitudinal increment between successive orbits, several methods can be used to determine future equator crossing times and longitudes. Once these have been determined, the plotting board and tracking diagram can be used to graphically compute the antenna azimuth and elevation angles from any station to a polar orbiting satellite passing within reception range.

This tracking excercise illustrates the use of the APT Predict (TBUS) Bulletin contained in Appendix A (page A-14), and the plotting board and tracking diagram arrangement described in Appendix B, to track a satellite passing within receiving range of a station located at Wallops Station, Virginia[1]. In this excercise, azimuth and elevation angles will be determined at one-minute increments.

First, examine PART I, line 1, of the APT Predict (TBUS) Bulletin. This line identifies the Reference Orbit (#8749), the equator crossing time (16:16:53Z), longitude (11.46°W), period (102 minutes, 02 seconds), and longitudinal increment between successive orbits (25.50°).

Next, position the track at the equator crossing longitude of the Reference Orbit, as shown in Figure C-1. Remember that the equator crossing longitude of the Reference Orbit is always the northbound, or Ascending Node, position. Note that the satellite's path for this Reference Orbit does not fall within the "above zero degree elevation area", or acquisition circle. [The "above zero degree elevation area" is a circle (or ellipse) 28.1° from the center of the diagram. This area should already be outlined, in accordance with instructions in Appendix B.]

Observe the positions of the tic-marks at +1, +2 and +3. These tic marks correspond to the equator crossing positions of the next three orbits west of the Reference Orbit, and are 25.50° apart -- the longitudinal increment between orbits indicated in PART I. The position at +1 is 11.46°W + 25.50°= 36.96°W (37.0°is close enough, since fractions of degrees are difficult to read on this scale map) and corresponds to the ascending node of orbit #8750; +2 is at 11.46 + 2x25.50° or 62.46°W, corresponding to orbit #8751; +3 is at 11.46°W + 3x25.50° or 87.96°W (88.0° is close enough) and corresponds to orbit #8752.

When the overlay on which the track is plotted is rotated to the equatorial positions corresponding to +1 and +2, the satellites' path passes within the acquisition circle. At +3, the path is west of the circle. Return the track to the position corresponding to +1. This will show the satellite crossing into the acquisition circle 09 minutes after the time of the ascending node, and remaining in range until minute 19.

[1] The shape of the tracking diagram will be different for different latitudes, and the position of the tracking diagram on the plotting board will depend upon the operator's station location. The method used to determine az/el angles, however, will be the same for any location.

Since orbital period equals 102 minutes 02 seconds, and since the Reference Orbit equator crossing time was 16:16:53Z, then the Reference Orbit +1 equator crossing time will be 17:58:55Z. The satellite signal will be acquired 9 minutes later -- at 18:07:55Z. It will remain within acquisition range for ten more minutes (until minute 19 AAN), or until 18:17:55Z.

Times for Orbit +2 after the Reference Orbit are computed the same way. Set the track to the equator crossing position of this orbit (62.46°W), as shown in Figure C-2. Observe that the satellite will be within the acquisition circle from minute 04 to minute 19. The equator crossing time for this orbit is 19:40:57Z (two times the orbital period added to the equator crossing time of the Reference Orbit). The satellite will come within acquisition range 4 minutes later, at 19:44:57Z, and pass out of range 19 minutes after the time of the Ascending Node, or at 19:59:57.

Look at the APT TRACKING WORKSHEET on the following page. The information at the top identifies the receiving station, spacecraft, and orbit number, date, equator crossing longitude and time for the orbit. The first column marked TIME (AAN) shows the minutes After Ascending Node (AAN) during which the satellite is within receiving range. The second TIME column is the Z-time, or the Greenwich Mean Time corresponding to the number of minutes after the ascending node.

Elevation angles are obtained first by listing Great Circle distance values at each minute marker along the satellite's path, then converting these distances to elevation angles by referring to Table 5.1 (page 5-12).

Each of the concentric circles radiating from the center of the tracking diagram represent two degrees of Great Circle distance. A satellite passing directly over the station would have a Great Circle distance of 0° and a corresponding elevation angle of 90° (from Table 5.1) at the instant when the satellite is directly overhead. When the Great Circle distance equals 28.1°, the elevation angle from the station to the satellite would be zero (for a satellite orbiting the earth at an altitude of 850 km). To compute the elevation angle record the Great Circle distance for each minute the satellite is within acquisition range, then convert these values to elevation angles by extrapolating between the values listed in Table 5.1.

Azimuth angle is determined directly from the plotting board. Each line radiating from the center of the tracking diagram represents 10° of azimuth. Observe and record the azimuth angle at each one-minute marker along the path of the satellite.

The APT Worksheet on page C-3 shows how az/el has been computed for orbits #8750 and #8751.

APT TRACKING WORKSHEET

STATION: Wallops Station, Virginia SPACECRAFT: TIROS-N

DATE: 6/24 ORBIT: #1850 EQUATOR CROSSING LONG: 36.96°W TIME: 17:58:55Z

TIME *AAN	TIME (Z)	AZIMUTH (Deg.)	ELEV. (Deg.)	GREAT CIRCLE DISTANCE	HEIGHT (km)
09	$18^h07^m55^s$	97.0	12.5	26.0	
10	18:08:55	90.0	15.4	24.1	840
11	18:09:55	82.0	17.8	22.4	
12	18:10:55	75.0	18.5	22.0	840
13	18:11:55	66.0	19.4	21.6	
14	18:12:55	53.0	20.2	21.0	840
15	18:13:55	44.0	18.7	21.8	
16	18:14:55	36.0	18.1	22.4	840
17	18:15:55	27.0	15.8	24.2	
18	18:16:55	20.0	12.5	26.0	840
19	18:17:55	15.0	9.8	28.0	

APT TRACKING WORKSHEET

STATION: Wallops Station, Virginia SPACECRAFT: TIROS-N

DATE: 6/24 ORBIT: # 8751 EQUATOR CROSSING LONG: 62.46°W TIME: 19:40:57Z

TIME *AAN	TIME (Z)	AZIMUTH (Deg.)	ELEV. (Deg.)	GREAT CIRCLE DISTANCE	HEIGHT (km)
04	$19^h44^m57^s$	158.0	1.0	26.8	840
05	19:45:57	158.0	4.6	23.6	
06	19:46:57	157.5	10.1	19.4	840
07	19:47:57	155.0	16.0	15.8	
08	19:48:57	151.5	23.8	12.2	840
09	19:49:57	148.5	34.4	8.0	
10	19:50:57	135.0	51.2	5.2	840
11	19:51:57	100.0	60.9	2.6	
12	19:52:57	35.0	61.5	3.6	840
13	19:53:57	10.0	46.7	6.0	
14	19:54:57	358.0	30.8	9.8	840
15	19:55:57	355.0	21.4	13.2	
16	19:56:57	352.0	14.9	16.4	840
17	19:57:57	351.5	9.2	20.0	
18	19:58:57	351.0	3.9	23.8	840
19	19:59:57	350.0	1.7	26.2	

* AAN -- After Ascending Node

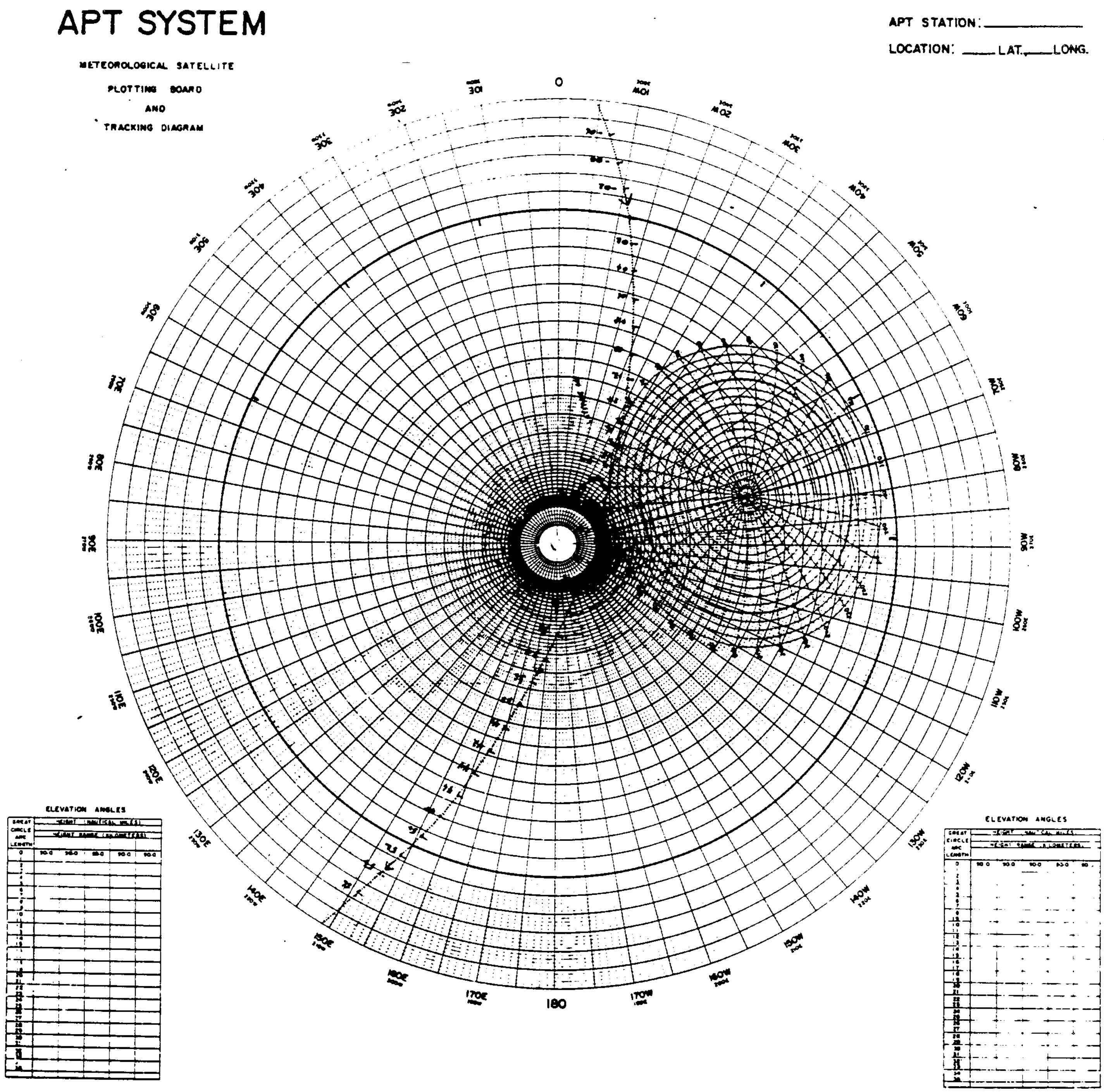


Figure C-1. Track set for Reference Orbit (#8749)

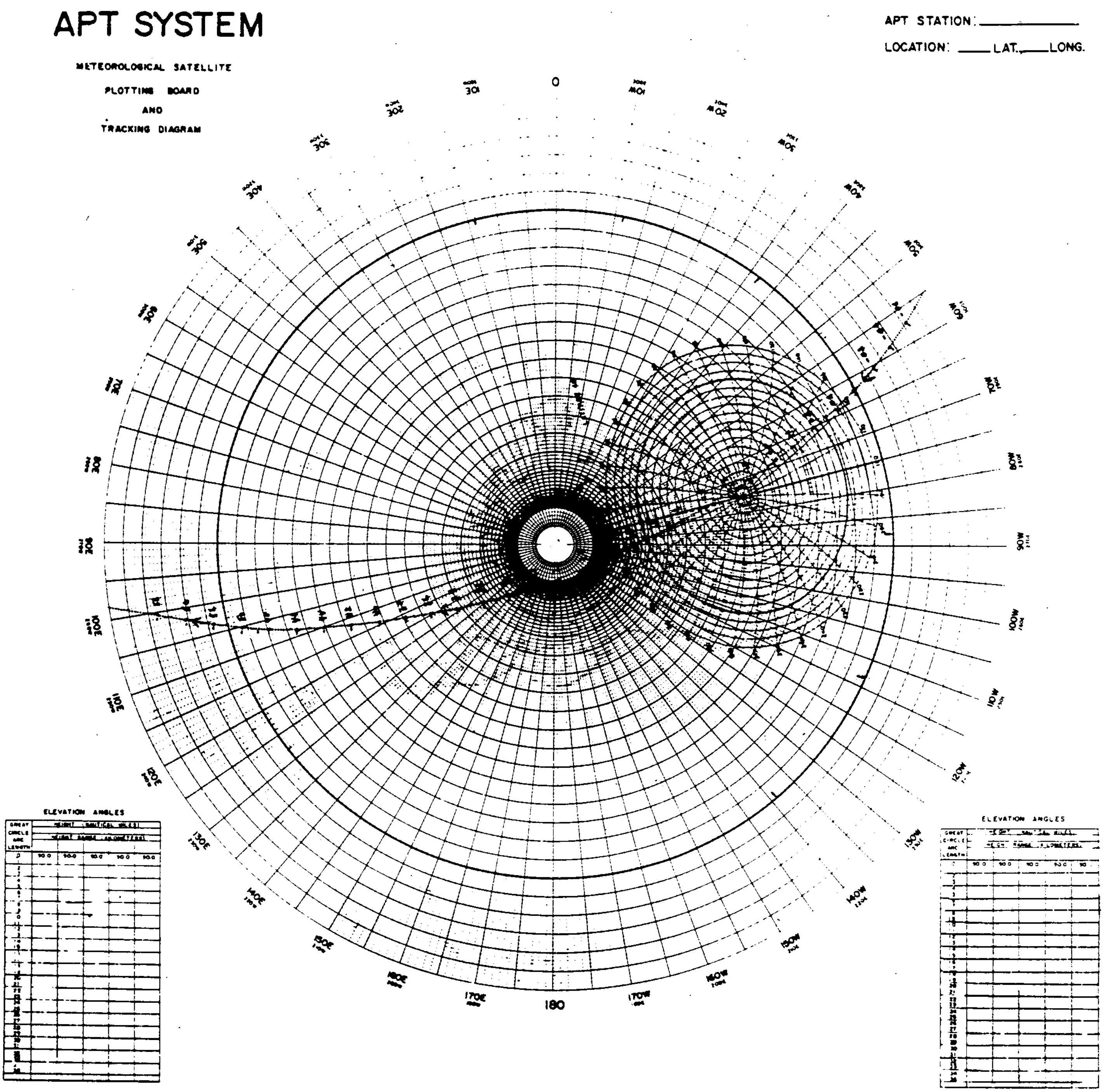


Figure C-2. Track set for Reference Orbit + 2 (#8751)

APPENDIX D

GRIDDING EXCERCISE

The gridding technique described in this section is based on the assumption that the station operator has a grid. Figure D-1 is a paper print of a grid produced by the National Earth Satellite Service (NESS) for use with TIROS-N series satellites. The original grid was produced on a 35mm film strip in both positive and negative form. (A copy of this film grid can be obtained from the Coordinator, Direct Readout Services). The user must first photographically enlarge the grid to the scale of his image, then produce a transparent film copy to use as an overlay on the image*.

This transparent grid overlay has a center line marking the subpoint track of the satellite, and one line along each edge parallel to the center line. These outer lines mark the picture edge, or horizon. Near-vertical dashed lines are longitude lines five degrees apart; latitude lines, also five degrees apart, are marked along the subpoint track. Numbers along the edge denote one-minute intervals beginning at time=0 at latitude 0°. Broad arrows indicate the direction of travel of the spacecraft.

On TIROS-N orbit #8751, an APT image was acquired at a satellite readout station close to Wallops Station, Virginia. The following exercise shows the steps used to fit a grid to this image.

The image acquisition time of orbit #8751 has already been determined in Appendix C. In brief, the time of the Reference Orbit (#8749) is given in PART I of the APT Predict (TBUS) Bulletin as 16:16:53Z, the period of a single orbit is 102 minutes 02 seconds, the equator crossing longitude is 11.46°W, and the longitudinal increment between orbits is 25.50°. Orbit #8751 is +2 orbits after the Reference orbit. Therefore, the equator crossing time and longitude of this orbit is easily calculated to occur at 19:40:57Z and 0° latitude, 62.46°W longitude.

Mark this point on the grid. The near-vertical dotted line intersecting the 0° latitude and 0-minute marker in Figure D-2 is the 62.45°W longitude line. Adjacent dotted longitude lines are five degrees apart and are appropriately marked 72.46°,67.46°, 57.46°, and 52.46°.

Now look at Figure D-3. Most users prefer to work with a conventional five-degree longitudinal grid system where 0° is the Greenwich Meridian, and successive five-degree longitudinal increments are marked off at 5°, 10°, 15°, etc. For this reason, longitude lines have been re-drawn on this "work' grid at 55°W, 60°W, 65°W, etc., by interpolating between the longitude lines indicated in Figure D-2.

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*This is not a universal APT grid, and cannot be used with all APT display devices due to differences in aspect ratios. With care and patience, APT station operators can develop their own grid overlays from a series of pictures.

Figure D-4 is the APT image acquired on orbit #8751. Figure D-5 shows this image with the "work" grid overlayed. Figure D-6 shows a retrace of the "work" grid overlayed on the image, smoothed to show only the conventional grid lines.

Some professional APT station operators prefer to have the grid electronically superimposed on the image during acquisition. This is an obvious advantage in offices where products used to prepare weather forecasts must be examined quickly. The only disadvanage is that the grid points can obscure significant featuuress on the image. Using a grid overlay has the advantage that the grid can be raised to examine image features.

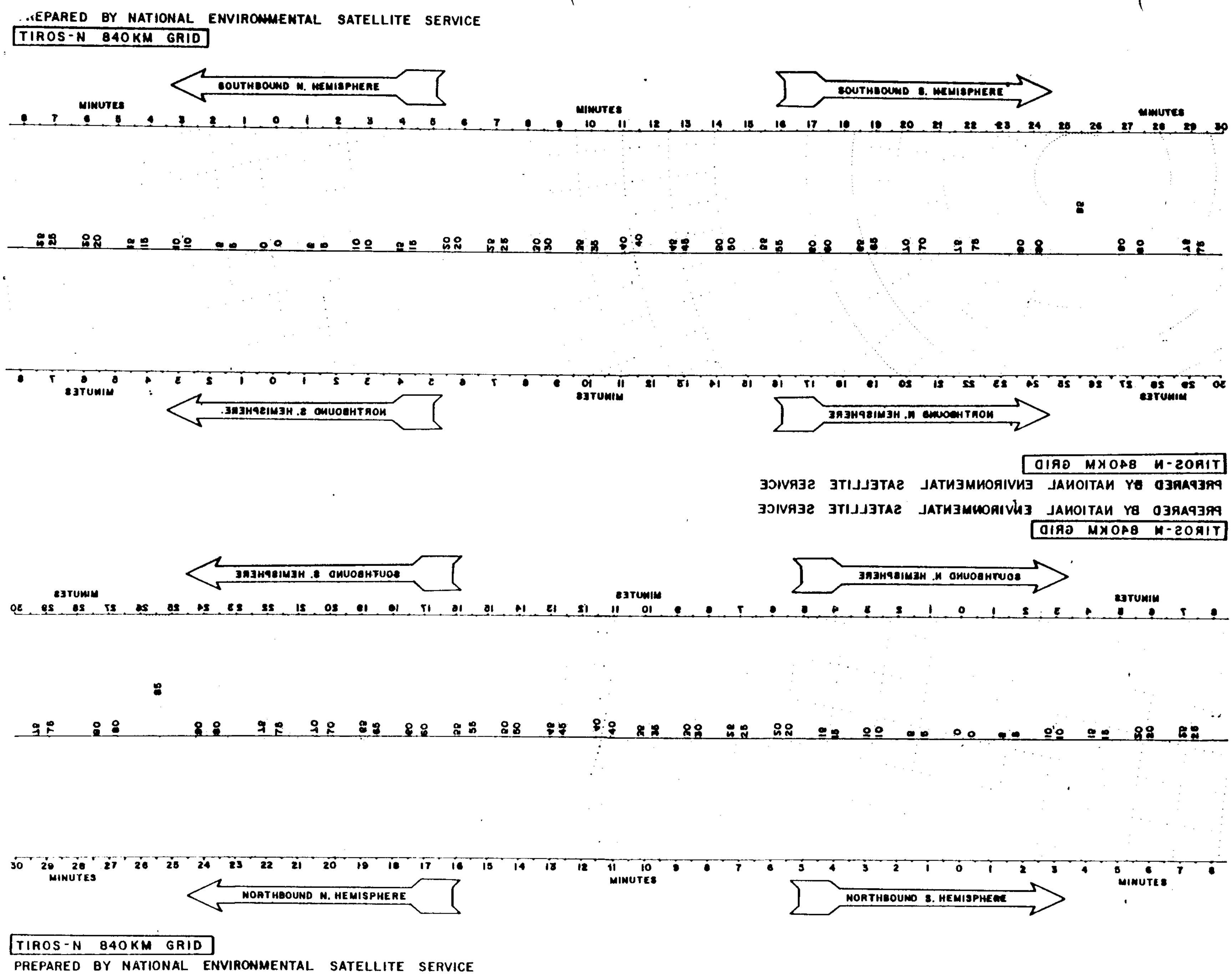

Figure D-1. TIROS-N series satellite APT 840km grid reproduced from 35mm film.

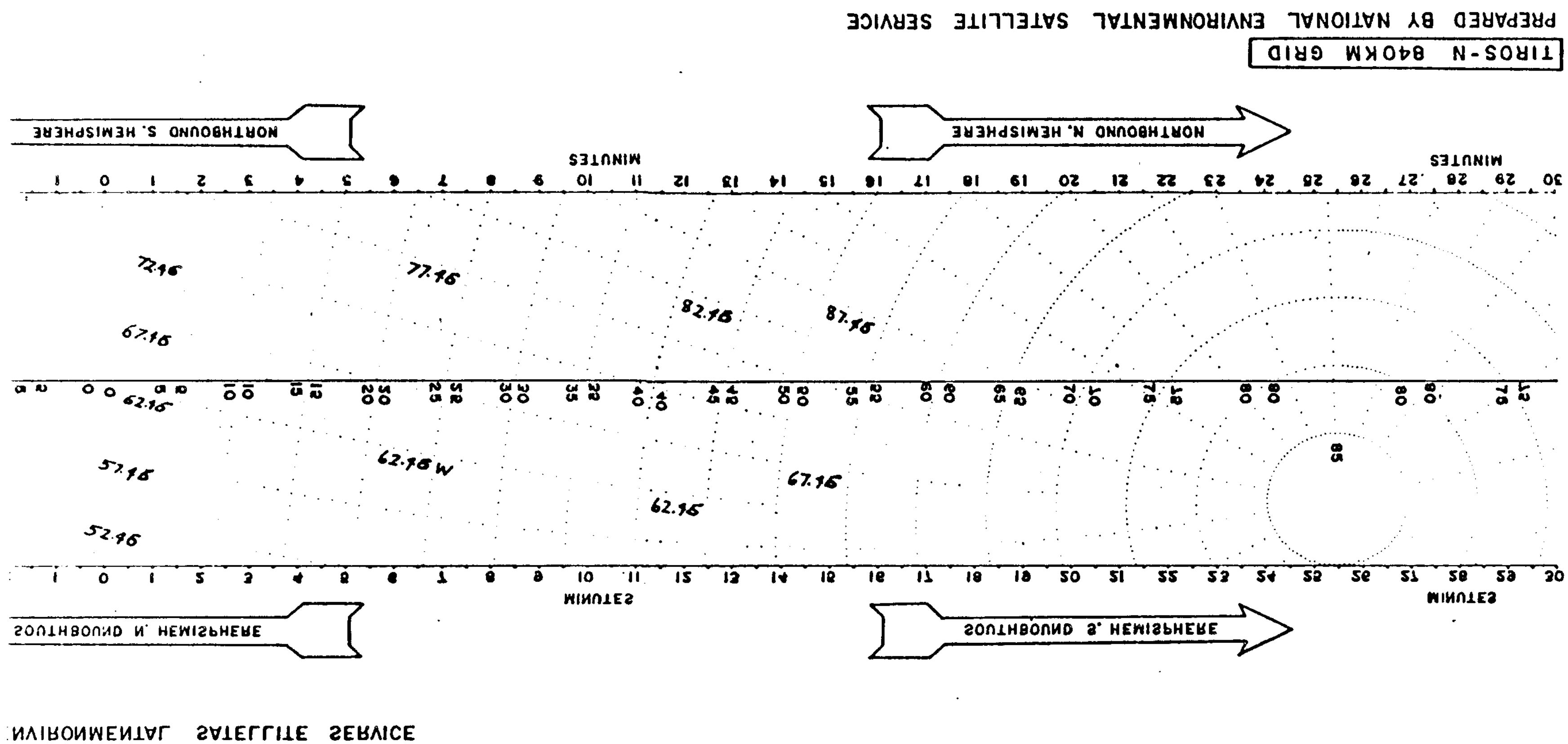

Figure D-2. Work grid. Section of grid with longitude annotations.

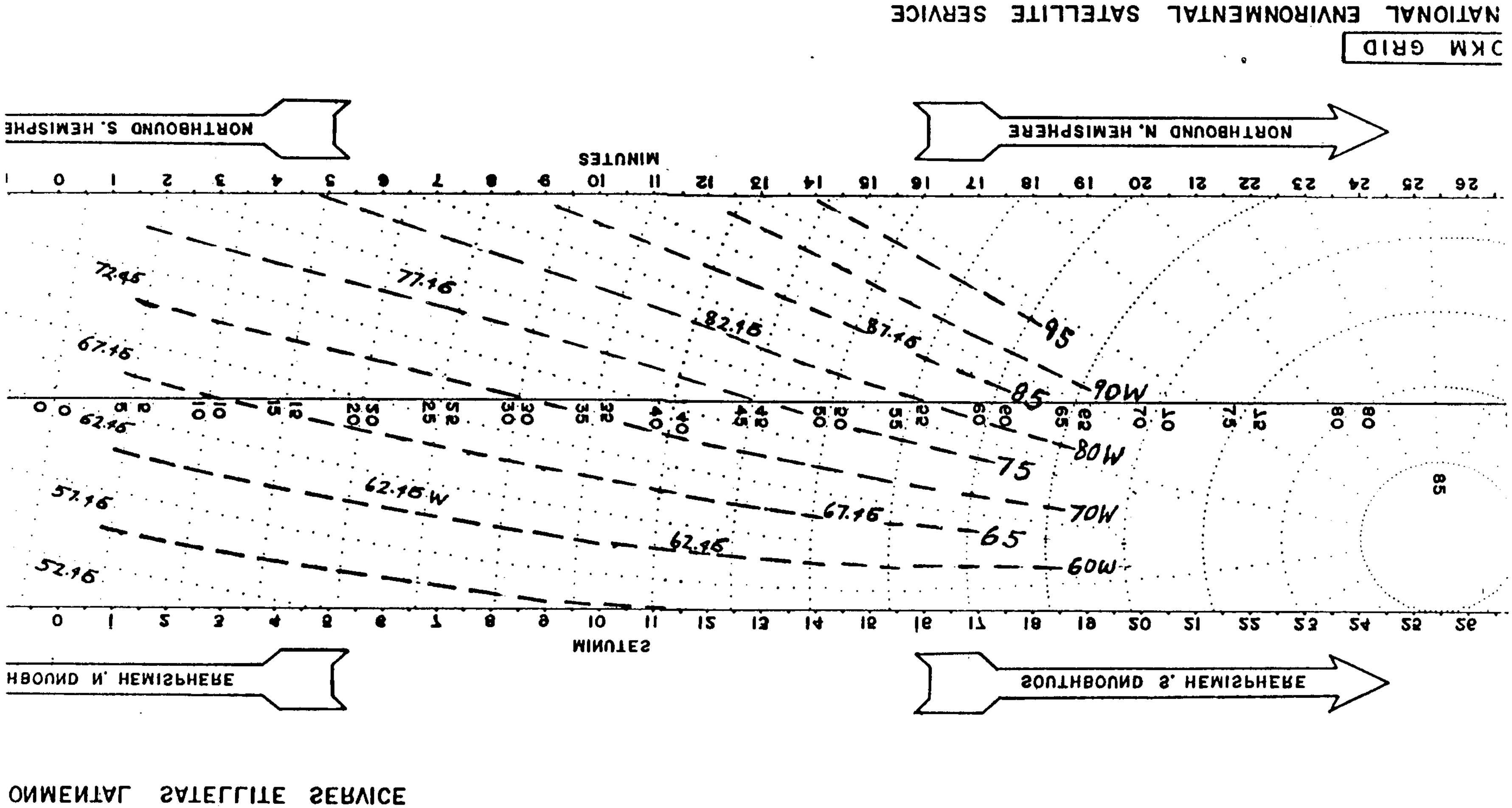

Figure D-3. Work grid with "conventional" longitude lines drawn by interpolating between previously marked lines.

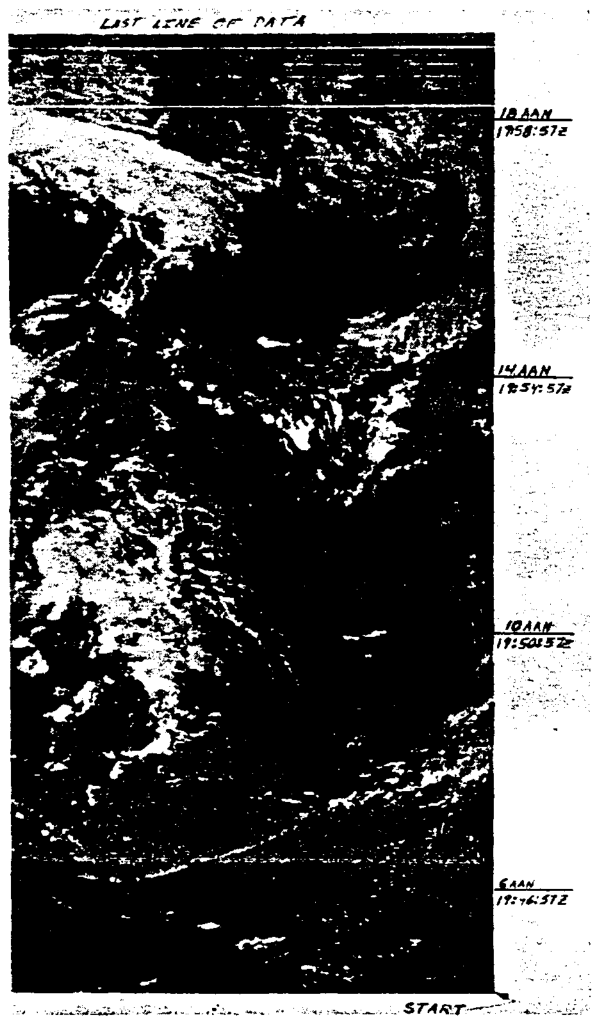

Figure D-4. APT image from orbit #8751.

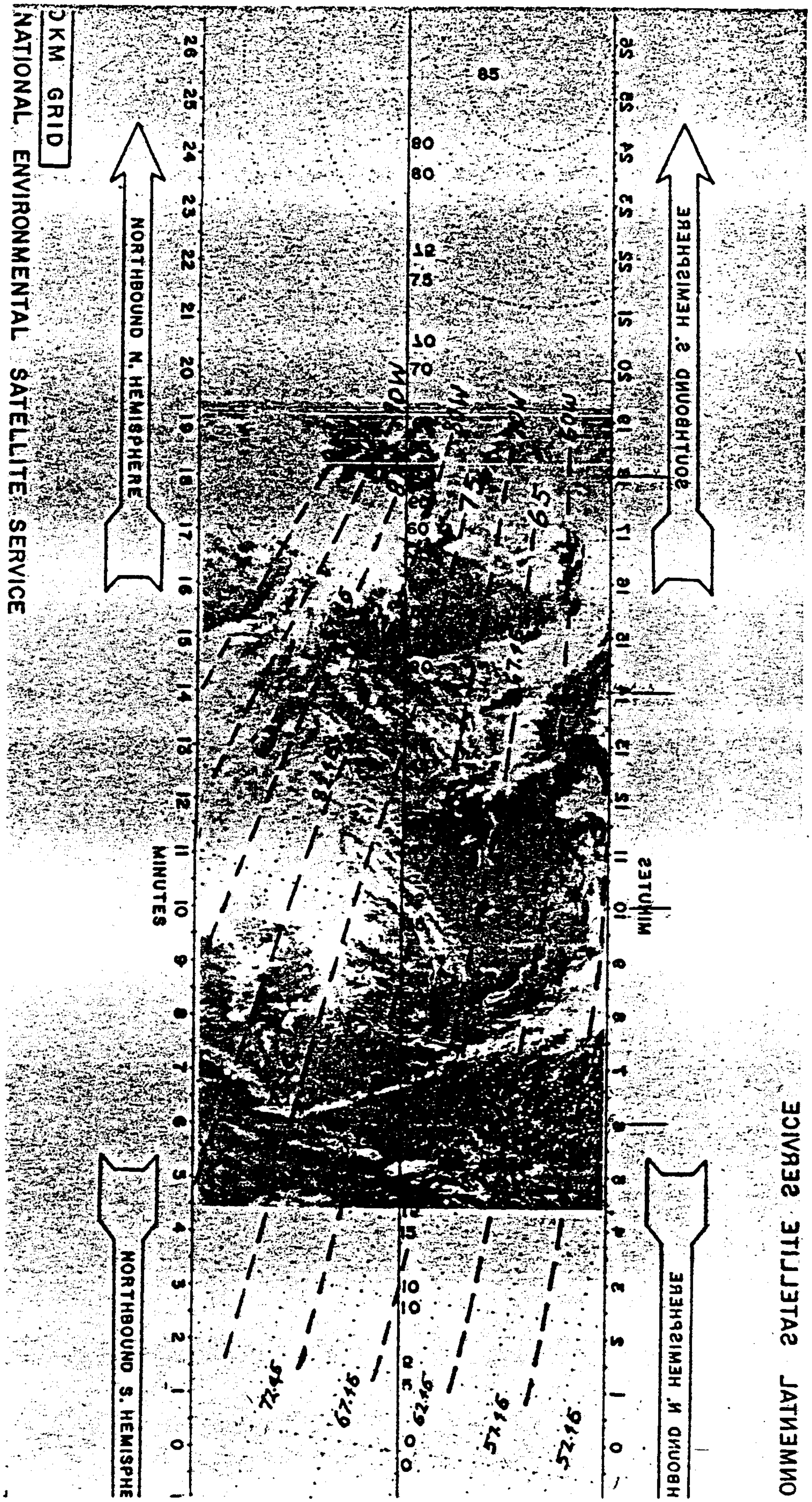

Figure D-5. APT image with work grid overlayed.

Figure D-6. APT image with smoothed grid overlayed.

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